Discovery of a Thorne-Żytkow Object Candidate in the Small Magellanic Cloud

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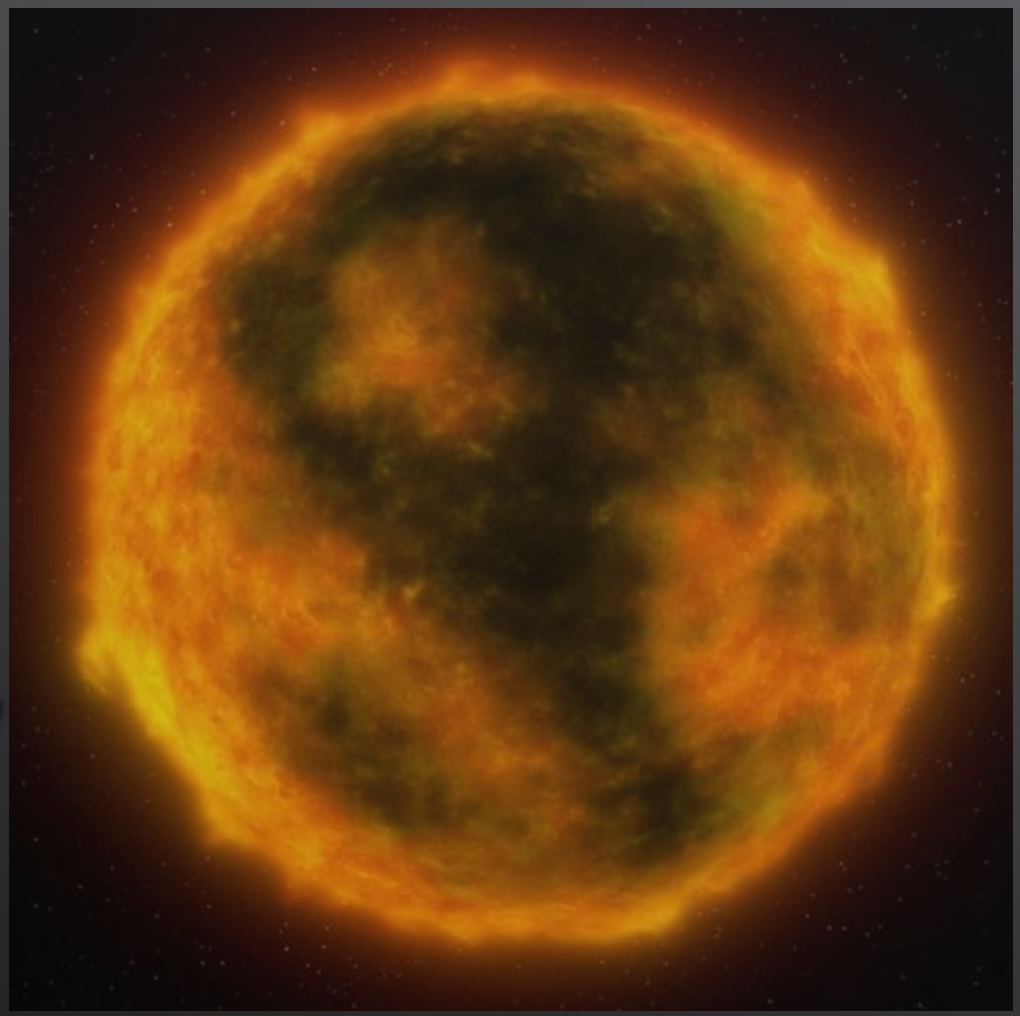
Thorne-Żytkow Objects (TŻOs) are a theoretical class of star: a neutron star "core" surrounded by a large diffuse envelope

- **Thorne & Żytkow (1977)** predict supergiant TŻOs (M_c = $1.0M_\odot$, $M_t \geq 11.5M_\odot$)

- Powered by a combination of thermonuclear reactions and gravitational accretion

- Represent a completely new model for stable stellar interiors.

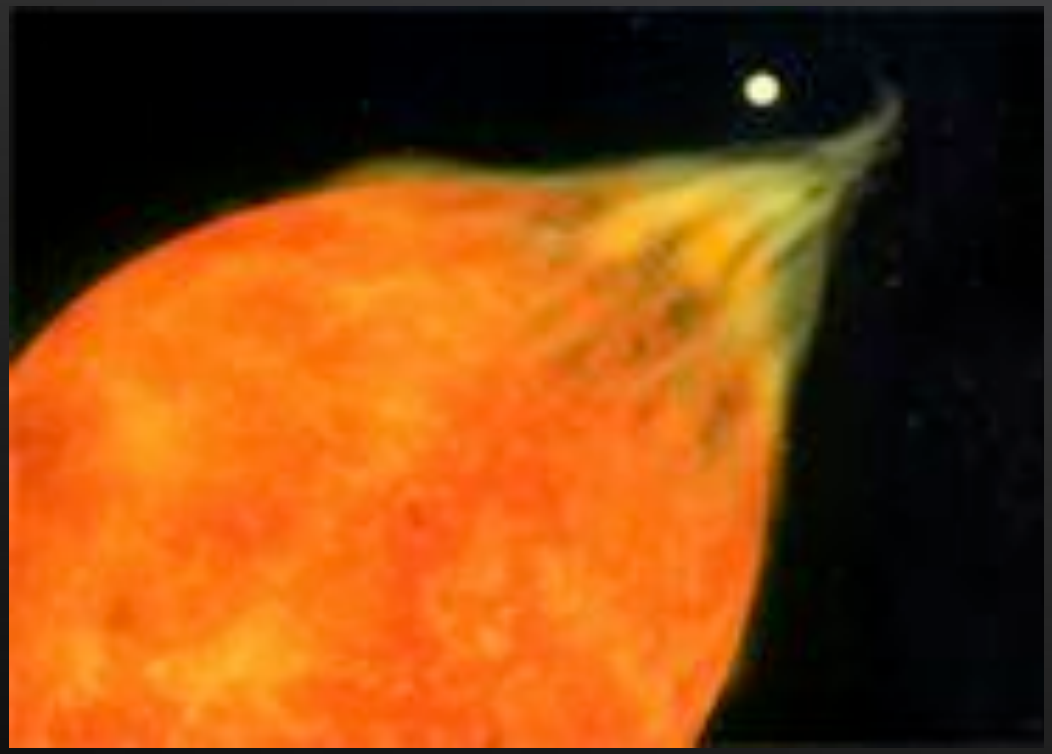


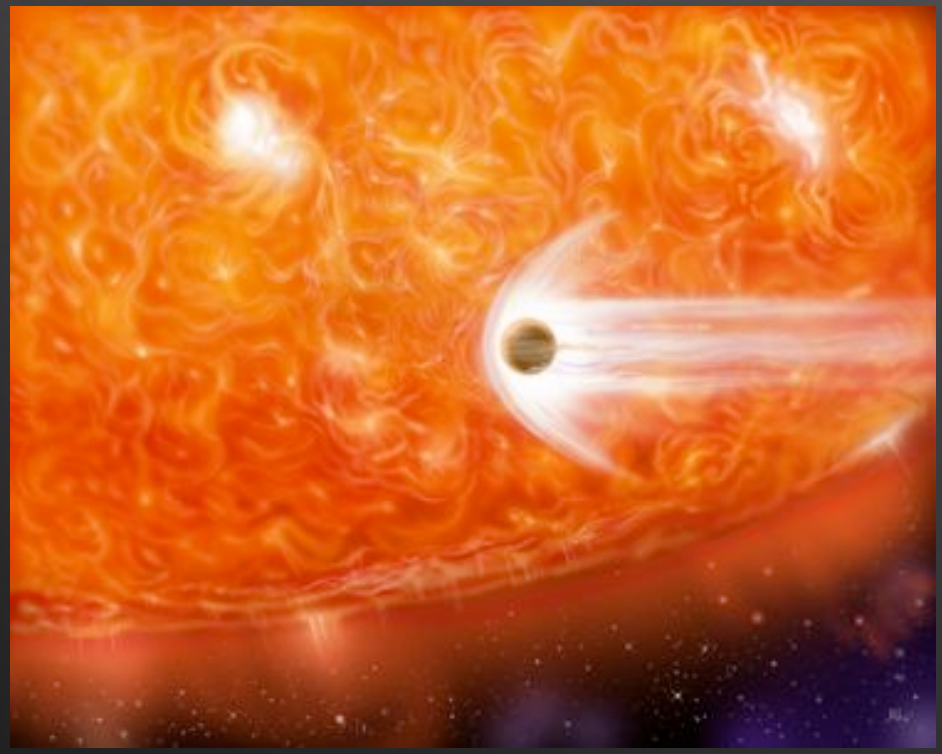
There has *never* been a confirmed observation of a TŻO.

Formation of TŻOs

1. Engulfing - an OB + NS HMXB; the OB companion leaves the main sequence, evolves into an RSG, expands, and engulfs the NS companion (Taam et al. 1978)

2. Collision - a massive binary system; one member collapses into a NS, and supernova kick velocity propels it into the massive companion (Leonard et al. 1994)





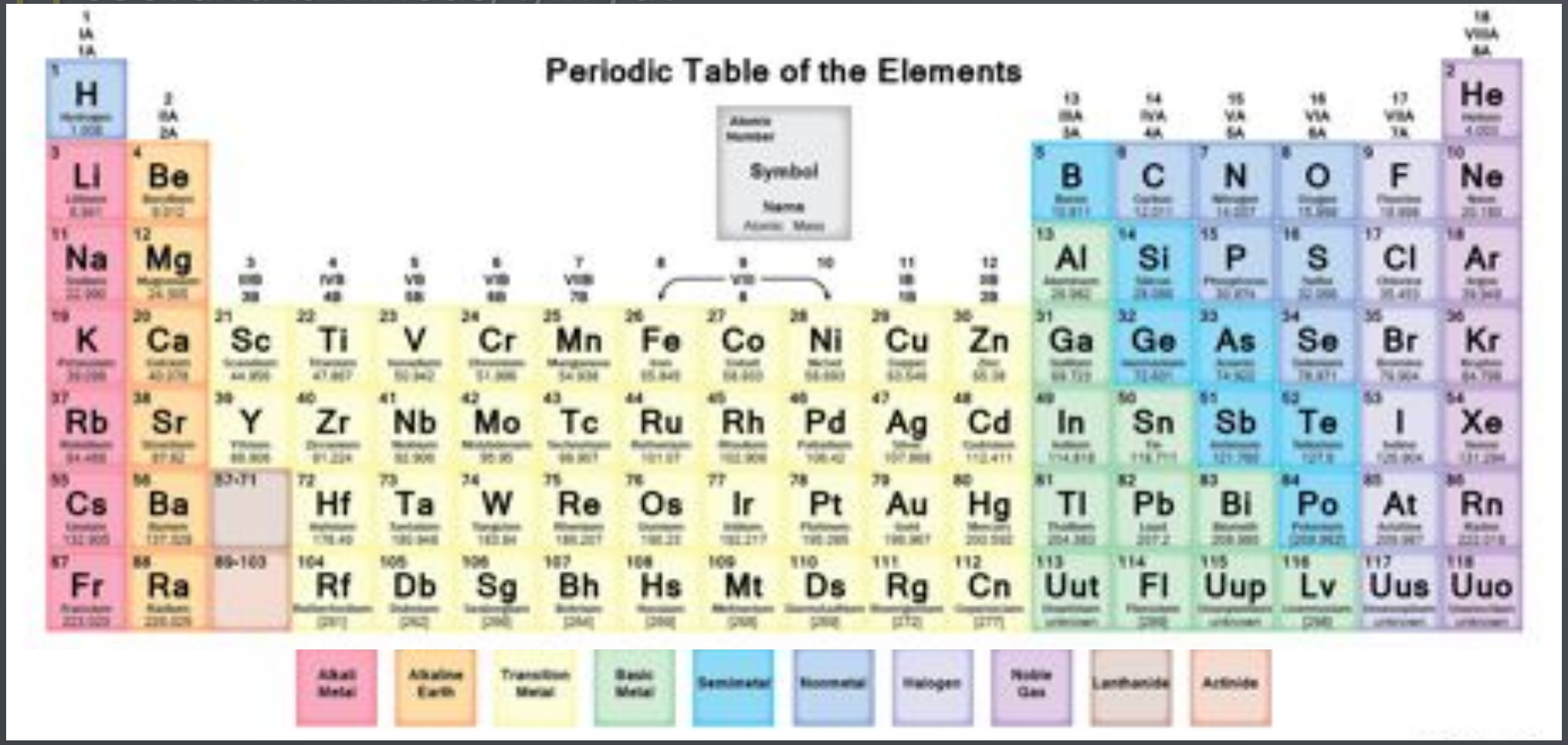
TŻOs are...

- cool and luminous, lying at or beyond the Hayashi limit for massive stars (Thorne & Żtykow 1977)
- strongly mass-losing as a result (van Paradijs et al. 1995)
- potentially more common at low Z (Linden et al. 2010)

metallicity

TŻOs are...

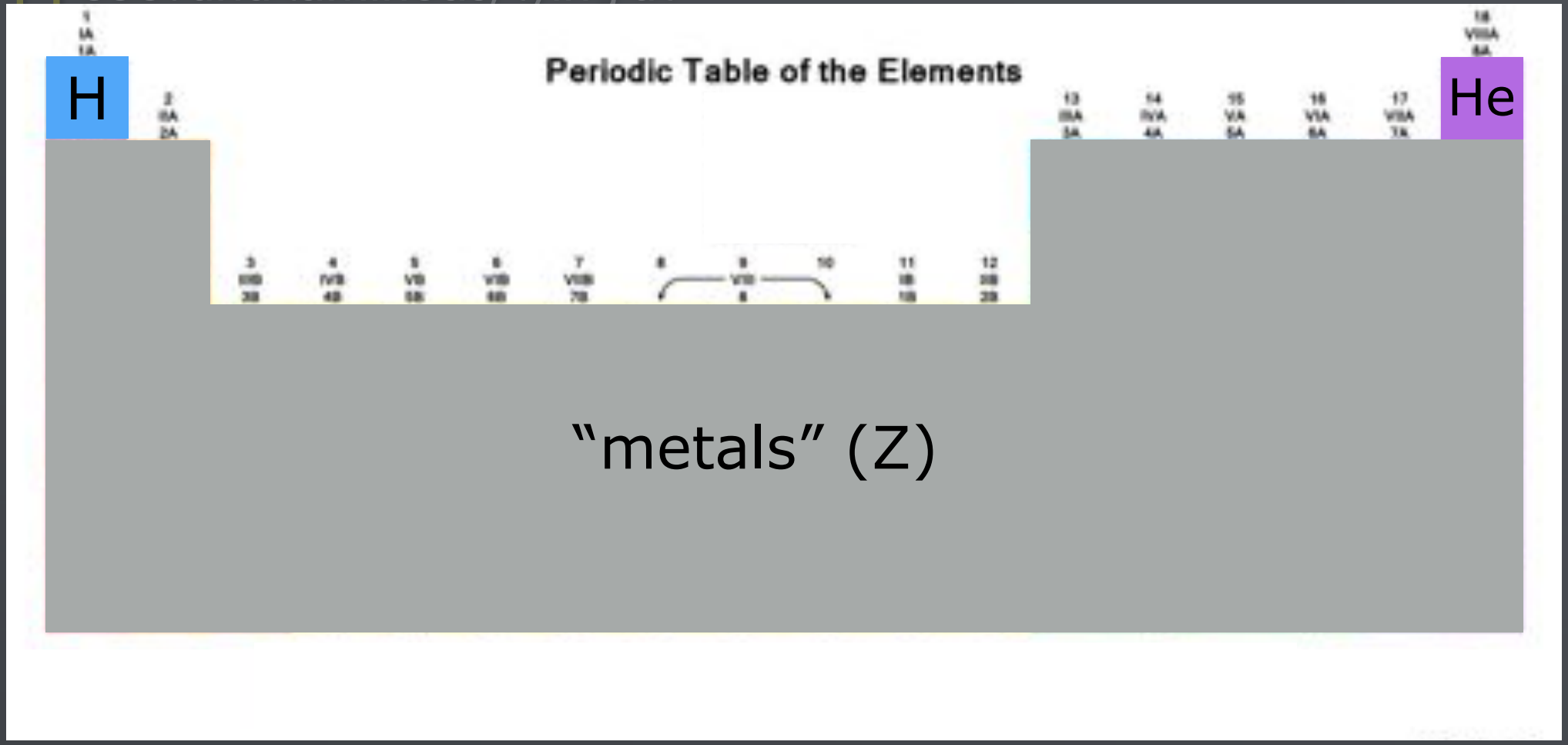
The periodic table...



TŻOs are...

astronomers'

The periodic table...



TŻOs are...almost indistinguishable from RSGs...

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metallicity

(anything beyond H and He)

TŻOs are...almost indistinguishable from RSGs...

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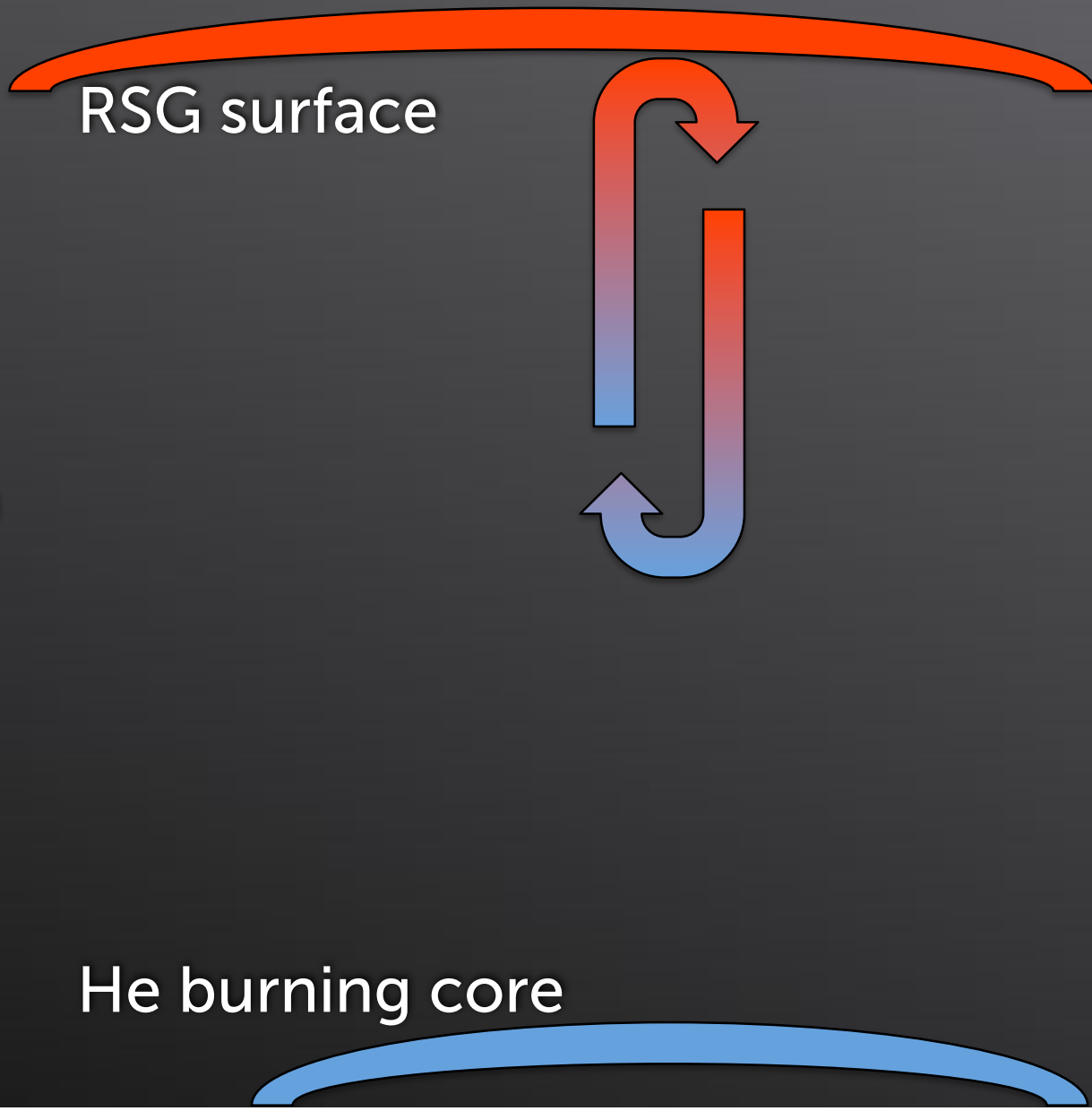
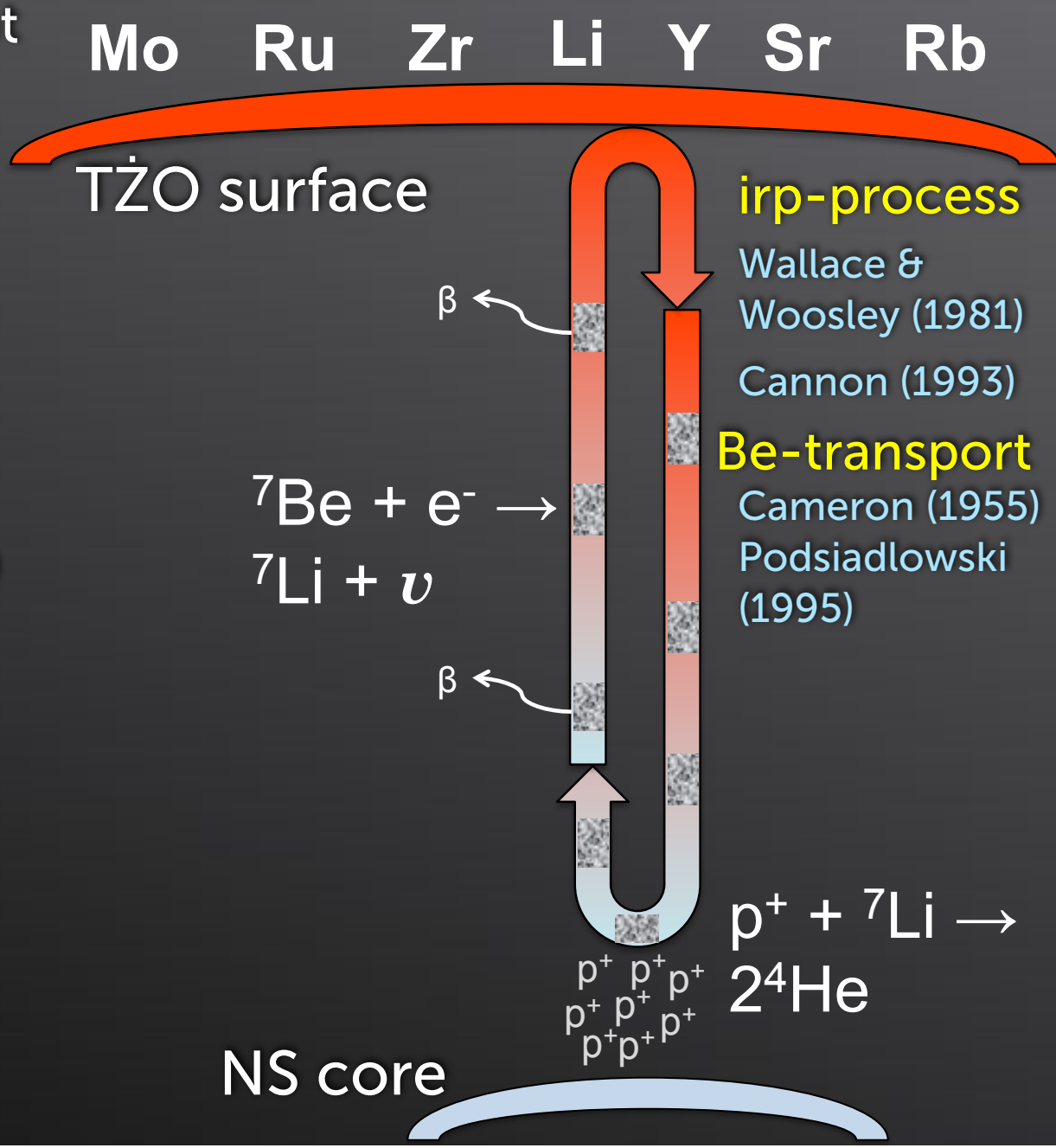


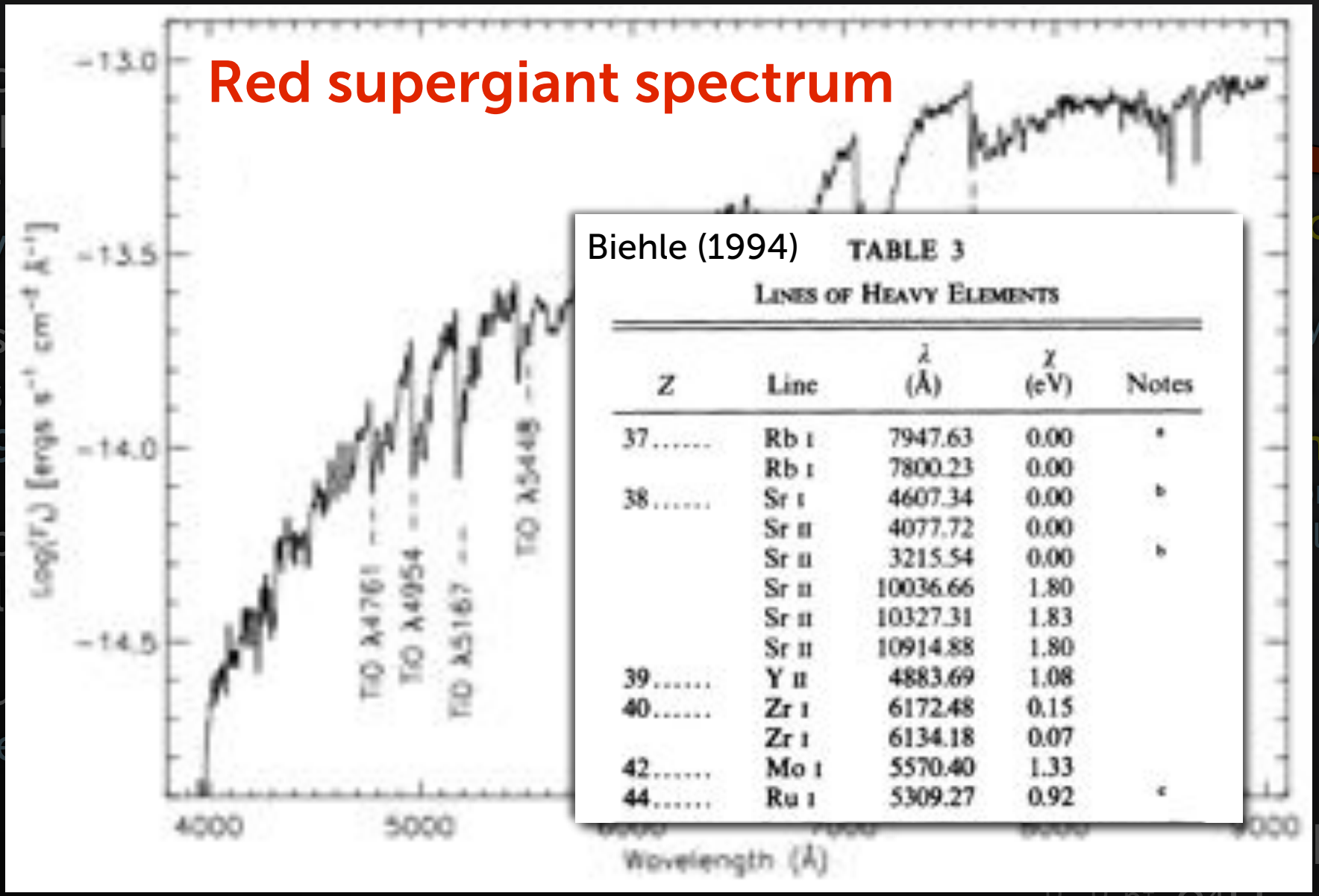
TŻOs are...almost indistinguishable from RSGs...

- cool and luminous, lying at or beyond the Hayashi limit for massive stars (Thorne & Żytkow 1977)
- strongly mass-losing as a result (van Paradijs et al. 1995)
- potentially more common at low Z (Linden et al. 2010)
- unique chemical profile (Biehle 1994)



TŻOs are...almost indistinguishable from RSGs...

Red supergiant spectrum



Biehle (1994) TABLE 3

LINES OF HEAVY ELEMENTS

Z	Line	λ (Å)	χ (eV)	Notes
37.....	Rb I	7947.63	0.00	a
	Rb I	7800.23	0.00	
38.....	Sr I	4607.34	0.00	b
	Sr II	4077.72	0.00	
	Sr II	3215.54	0.00	b
	Sr II	10036.66	1.80	
	Sr II	10327.31	1.83	
	Sr II	10914.88	1.80	
39.....	Y II	4883.69	1.08	
40.....	Zr I	6172.48	0.15	
	Zr I	6134.18	0.07	
42.....	Mo I	5570.40	1.33	
44.....	Ru I	5309.27	0.92	c

Rb

ocess

&

(1981)

(1993)

nsport

n (1955)

lowski

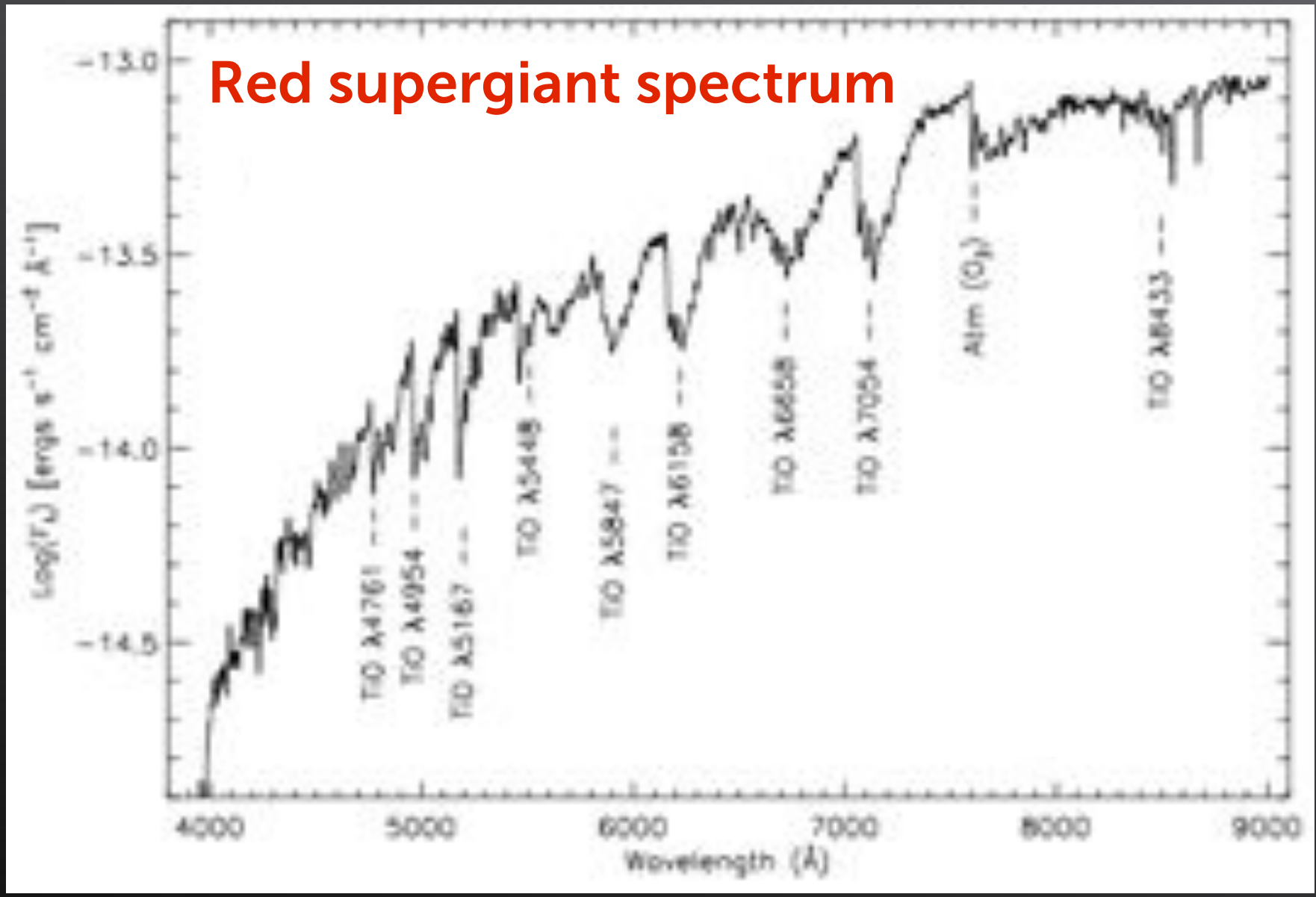
Li →

^{24}He

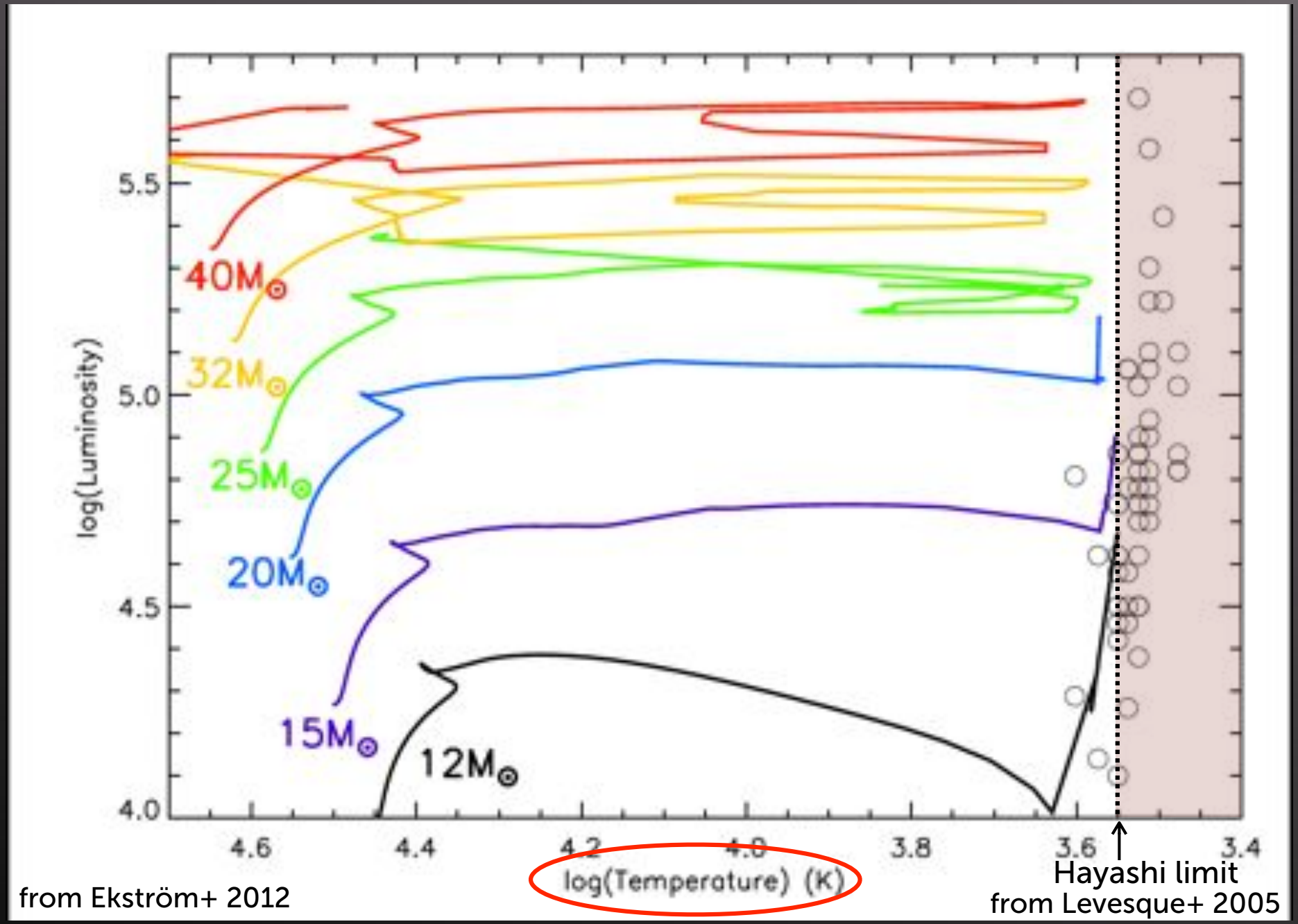
NS core

An effective large-scale search requires RSG samples with well-defined physical properties...

...but red supergiant spectra are difficult to model...



...and observations did not agree with theory...



from Ekström+ 2012

...and observations did not agree with theory...

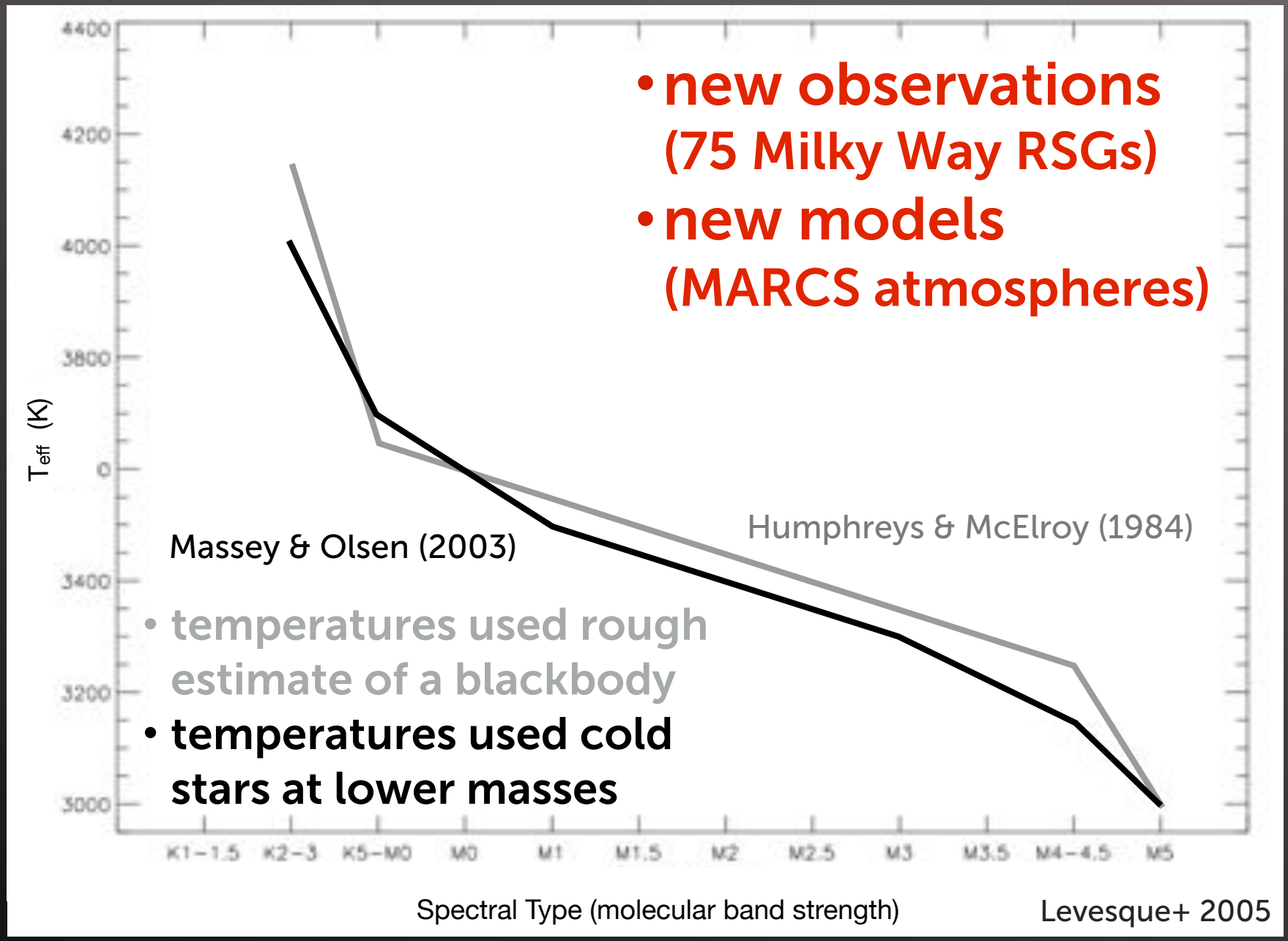
Step 1: Blame the theorists...

- uncertain molecular opacities
- high-velocity convective layers
- highly extended atmosphere
- treatment of mass-loss, rotation effects

Step 2: ...or could it be the data?

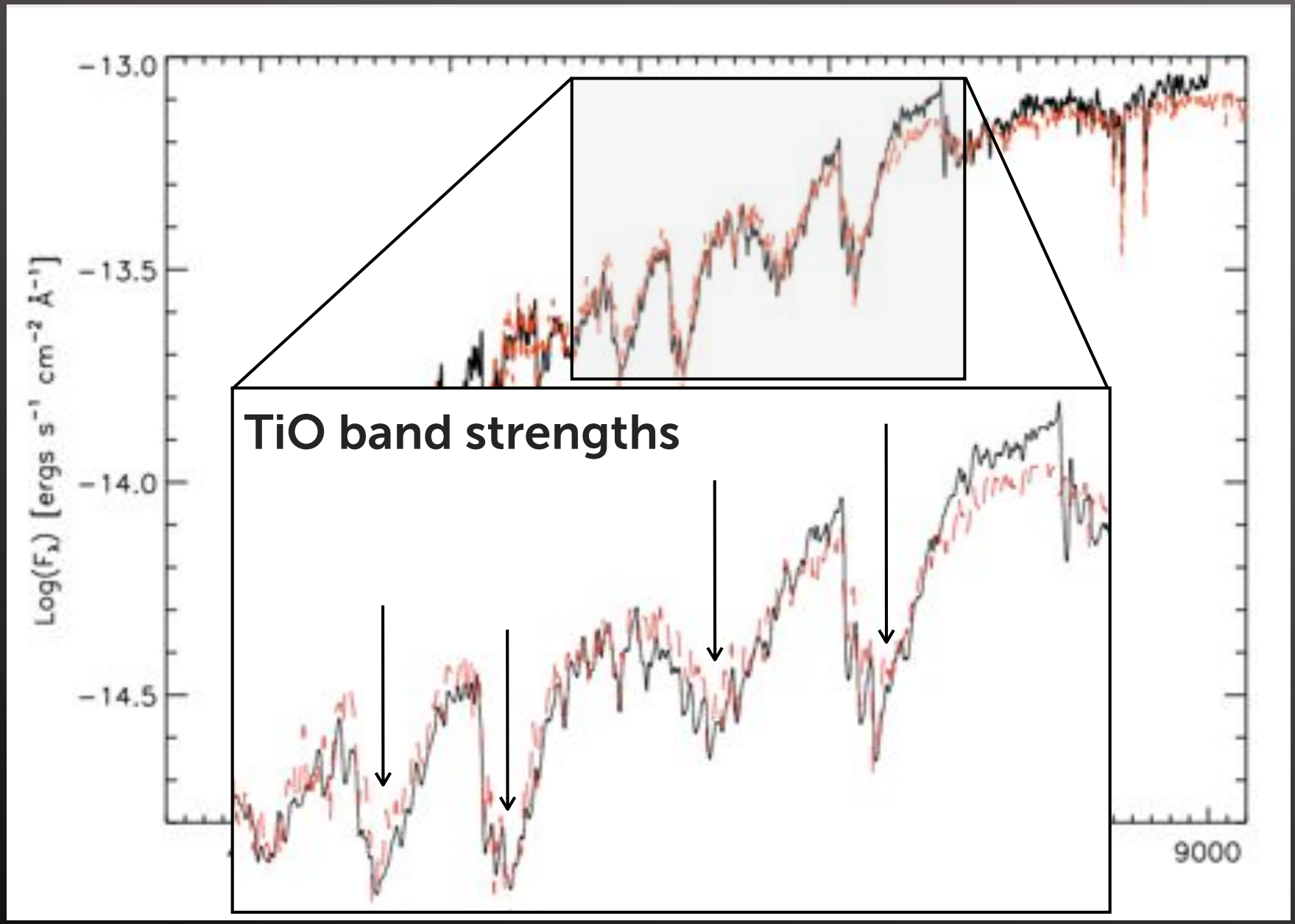
- specifically, could it be the temperatures?

...and observations ~~did not agree with theory...~~ had some problems!

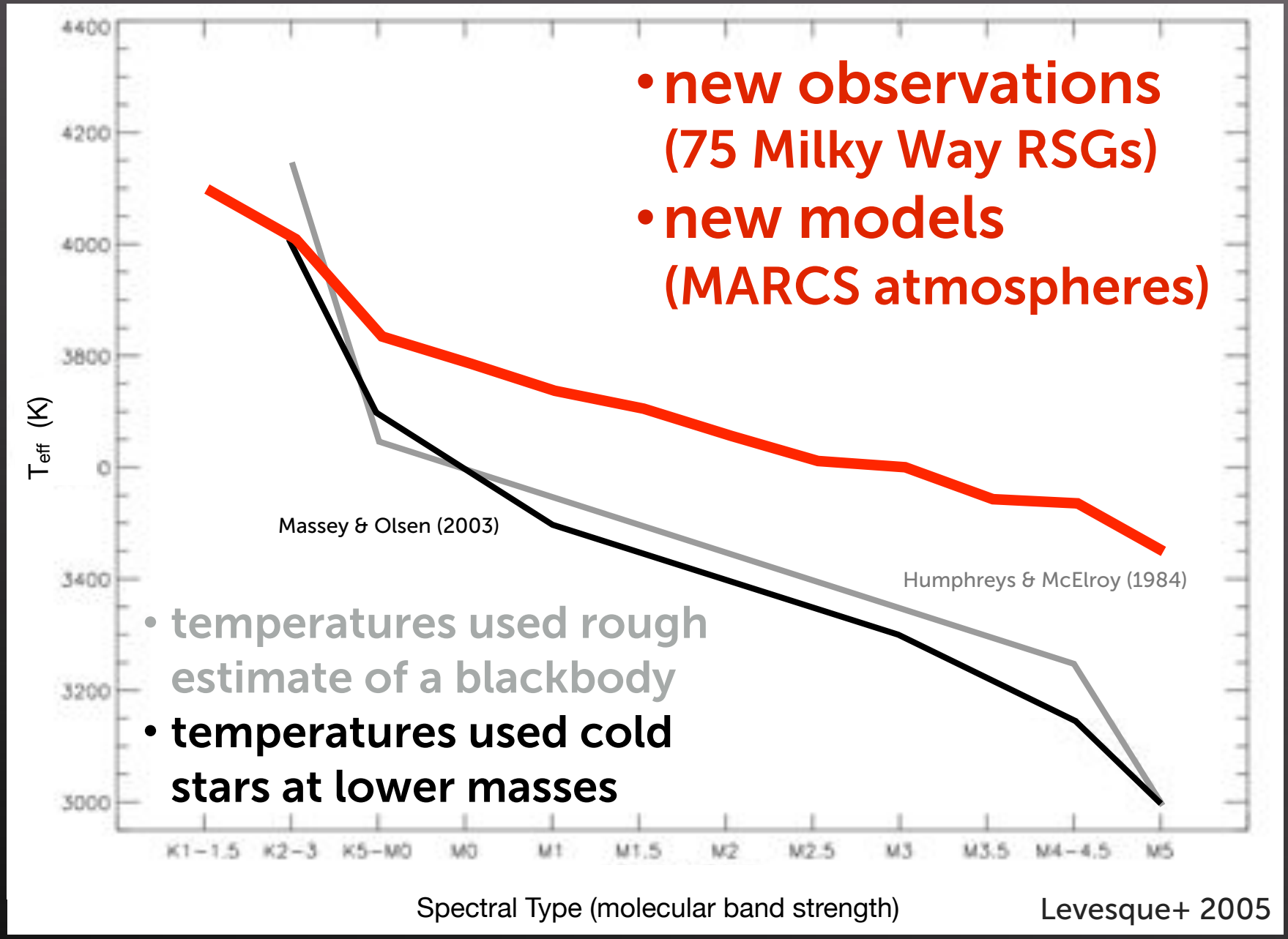


New Observations of RSGs

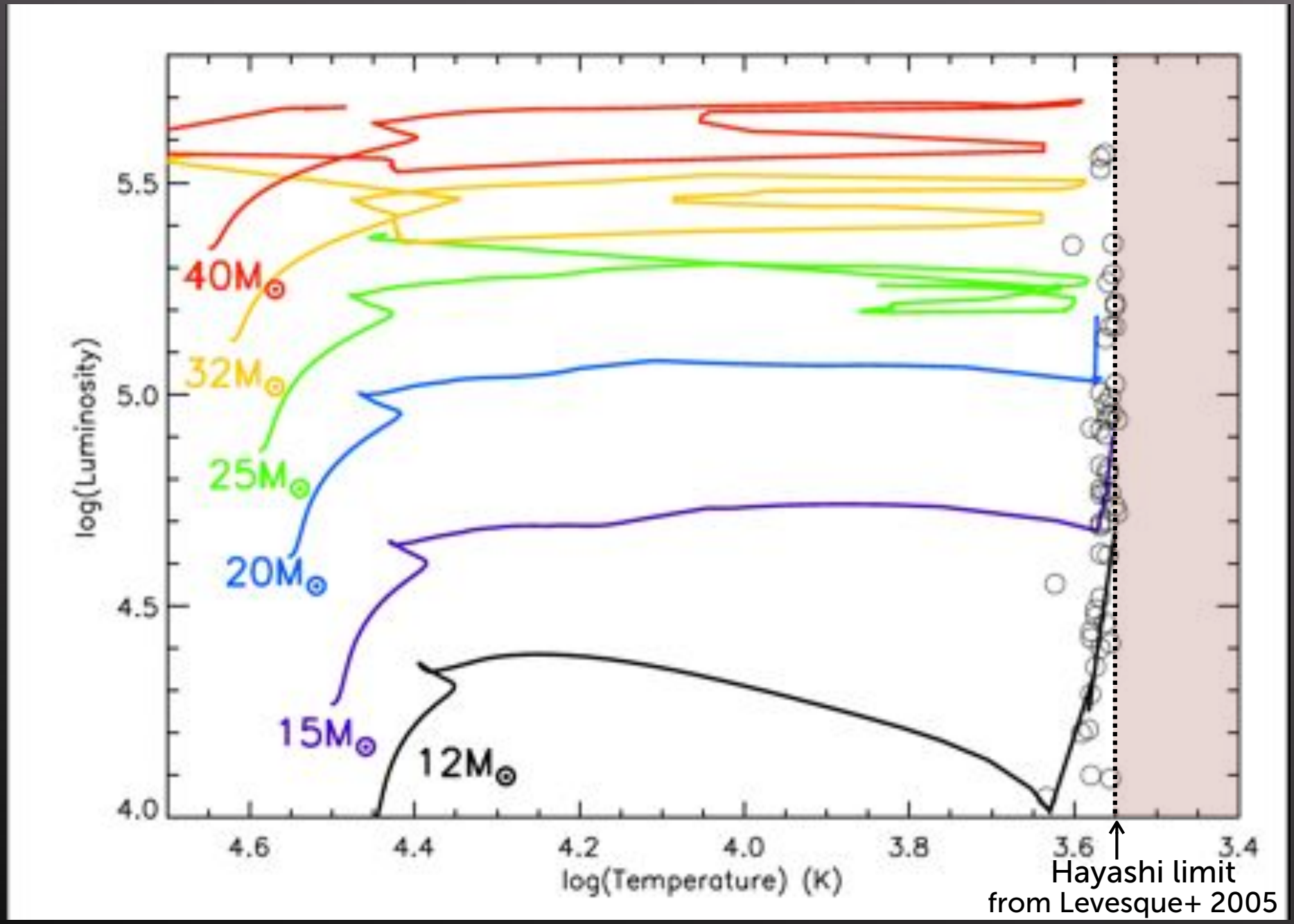
Fitting the spectra



New Observations of RSGs

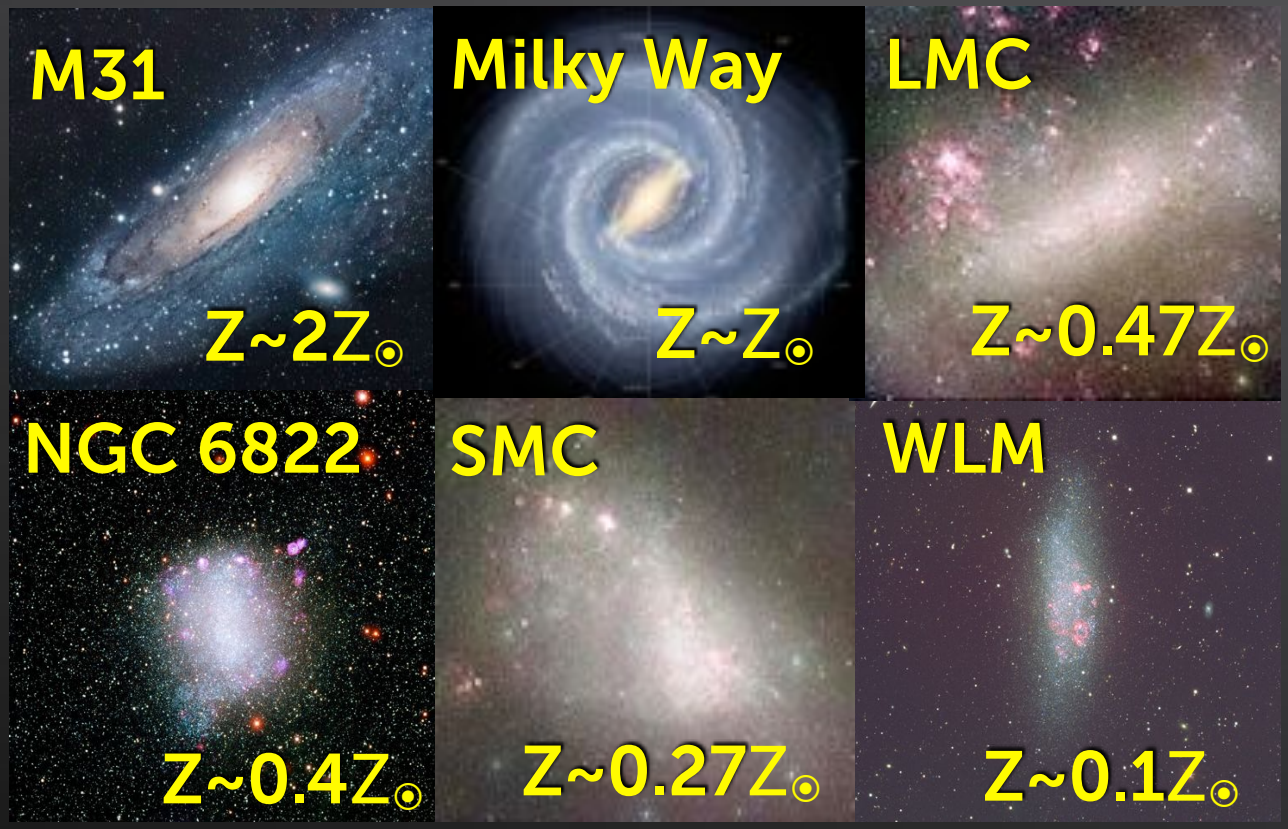


New Observations of RSGs

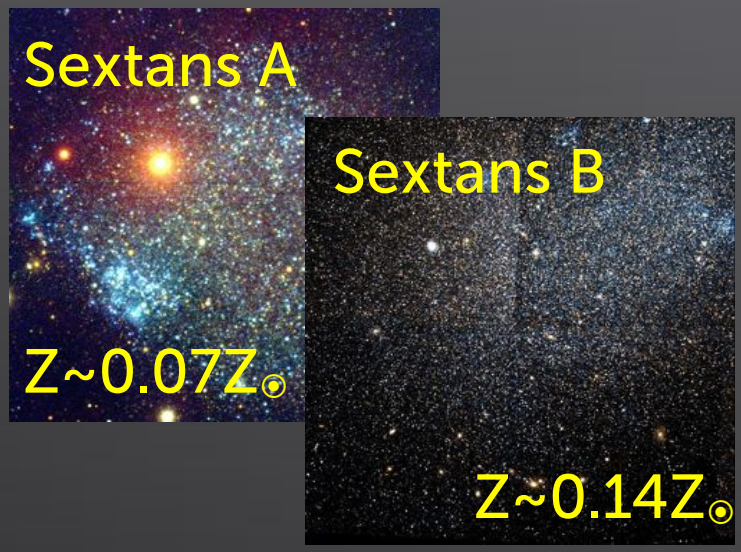


Defining RSG samples

Local Group

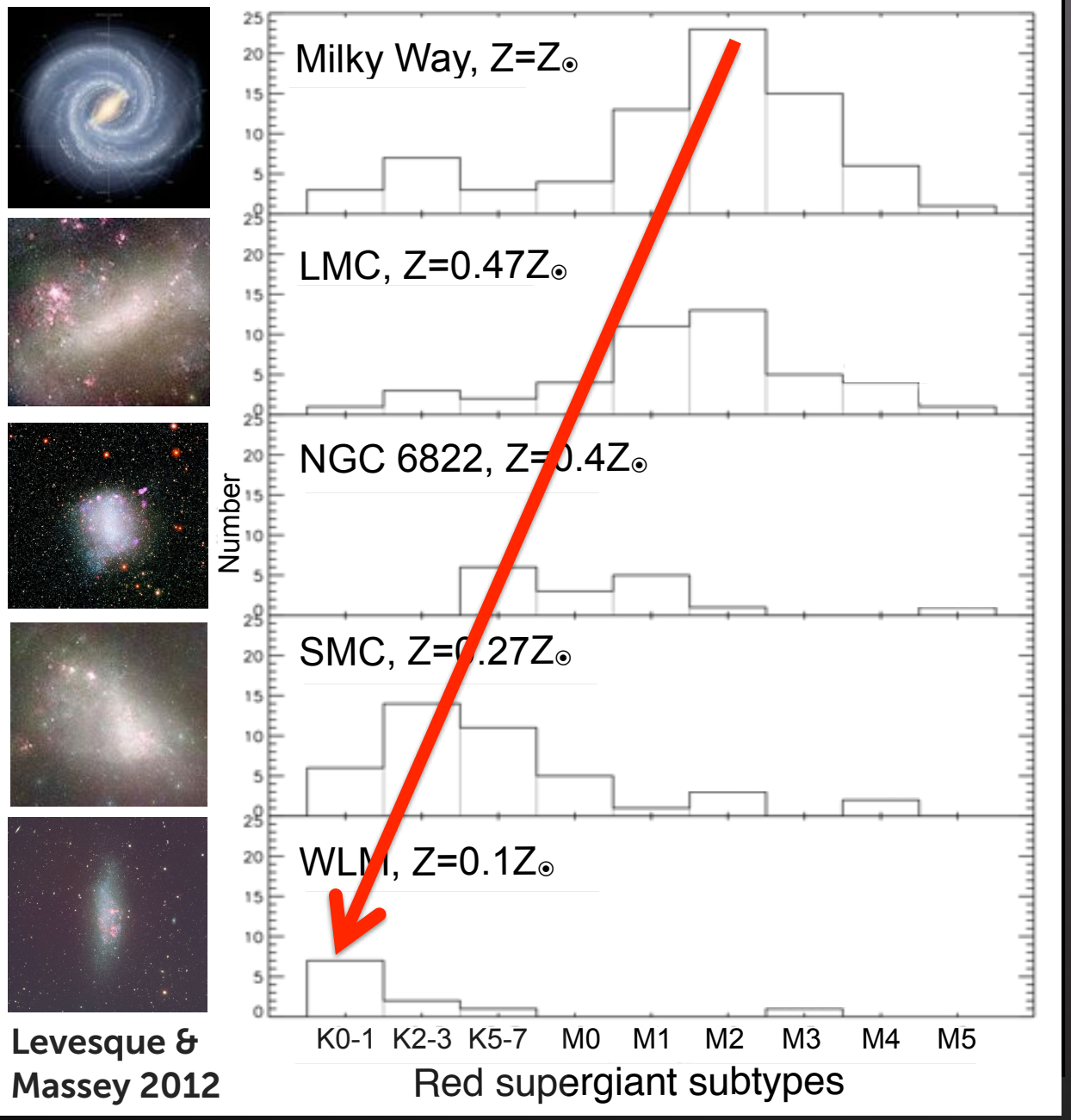


...and beyond!



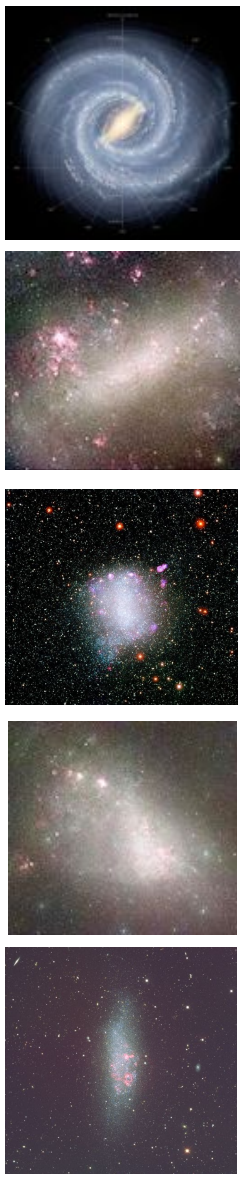
Weisenburger et al. (in prep)

Metallicity Effects

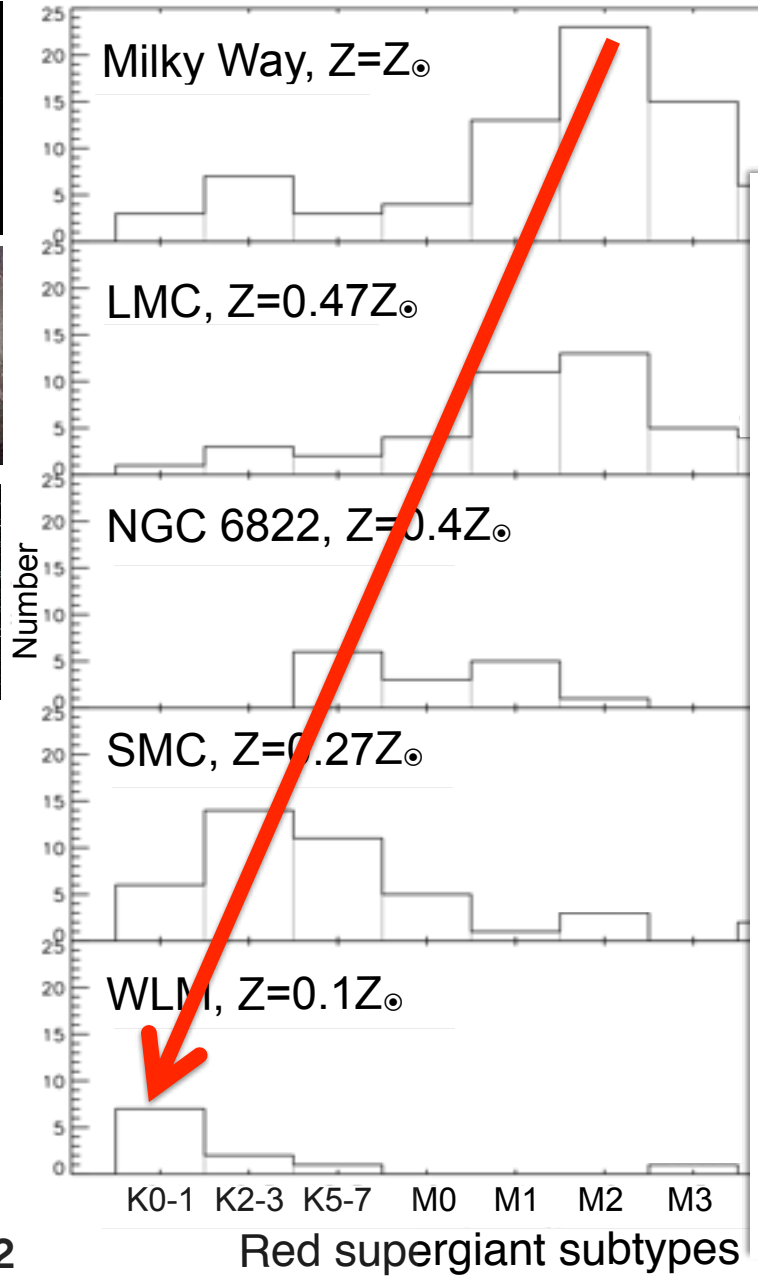


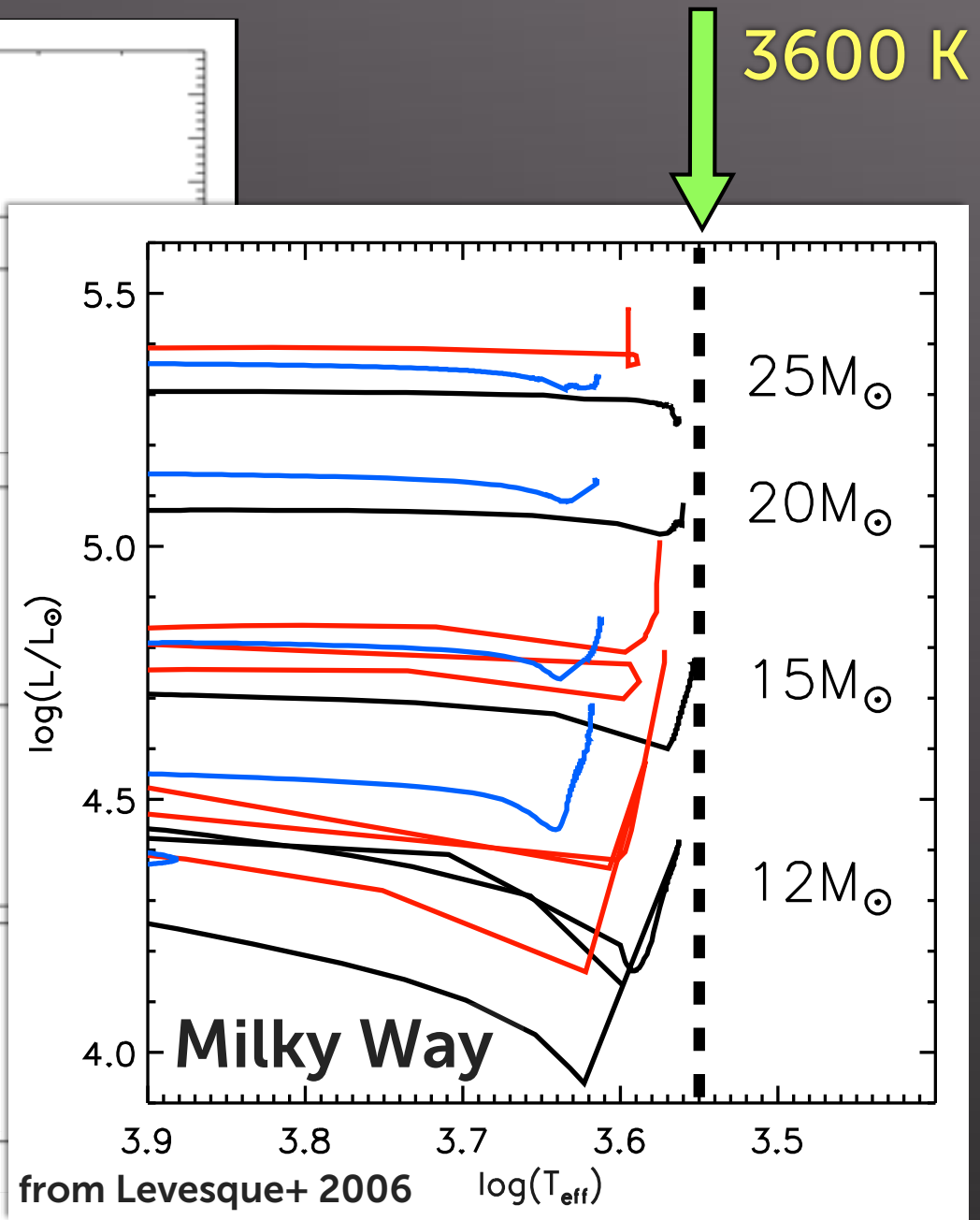
Levesque & Massey 2012

Metallicity Effects



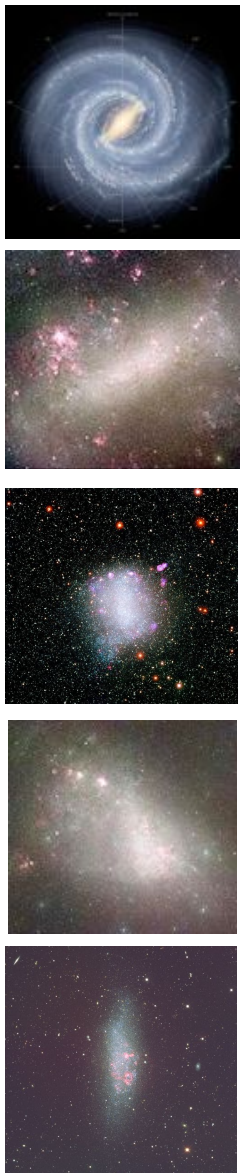
Levesque & Massey 2012



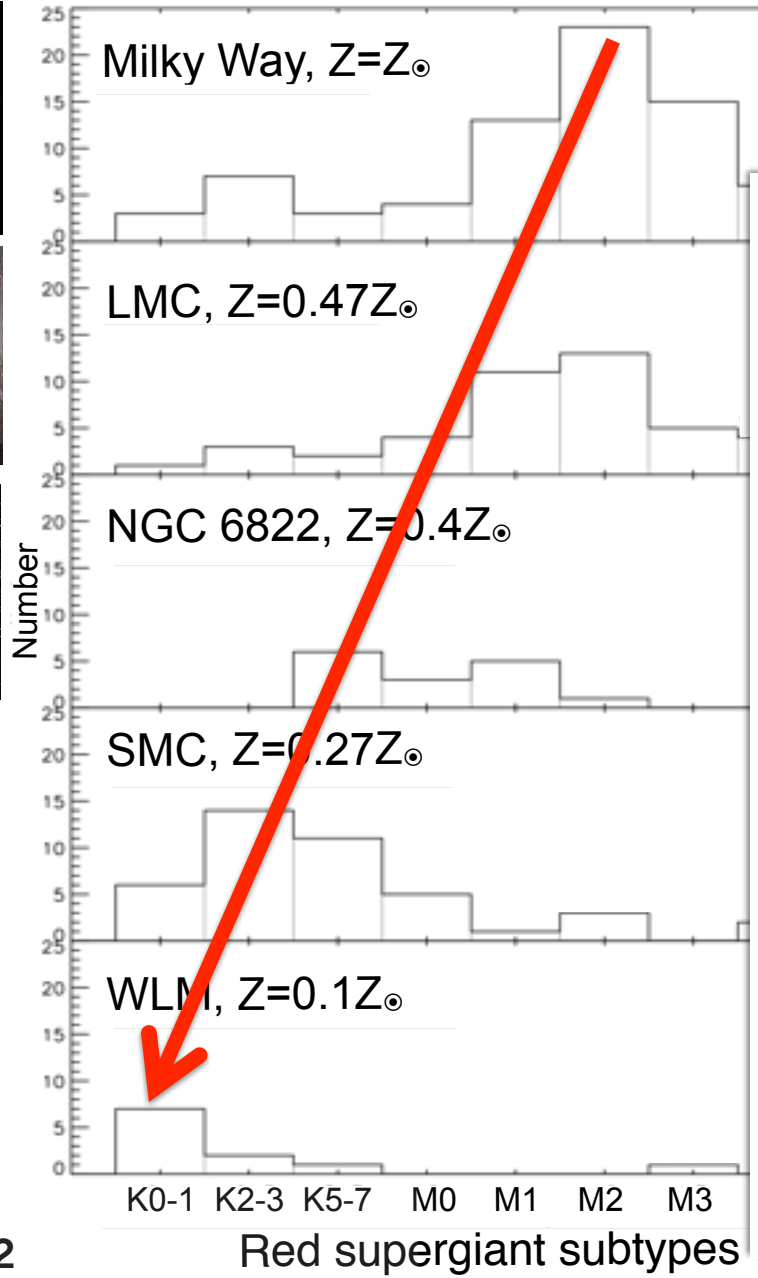


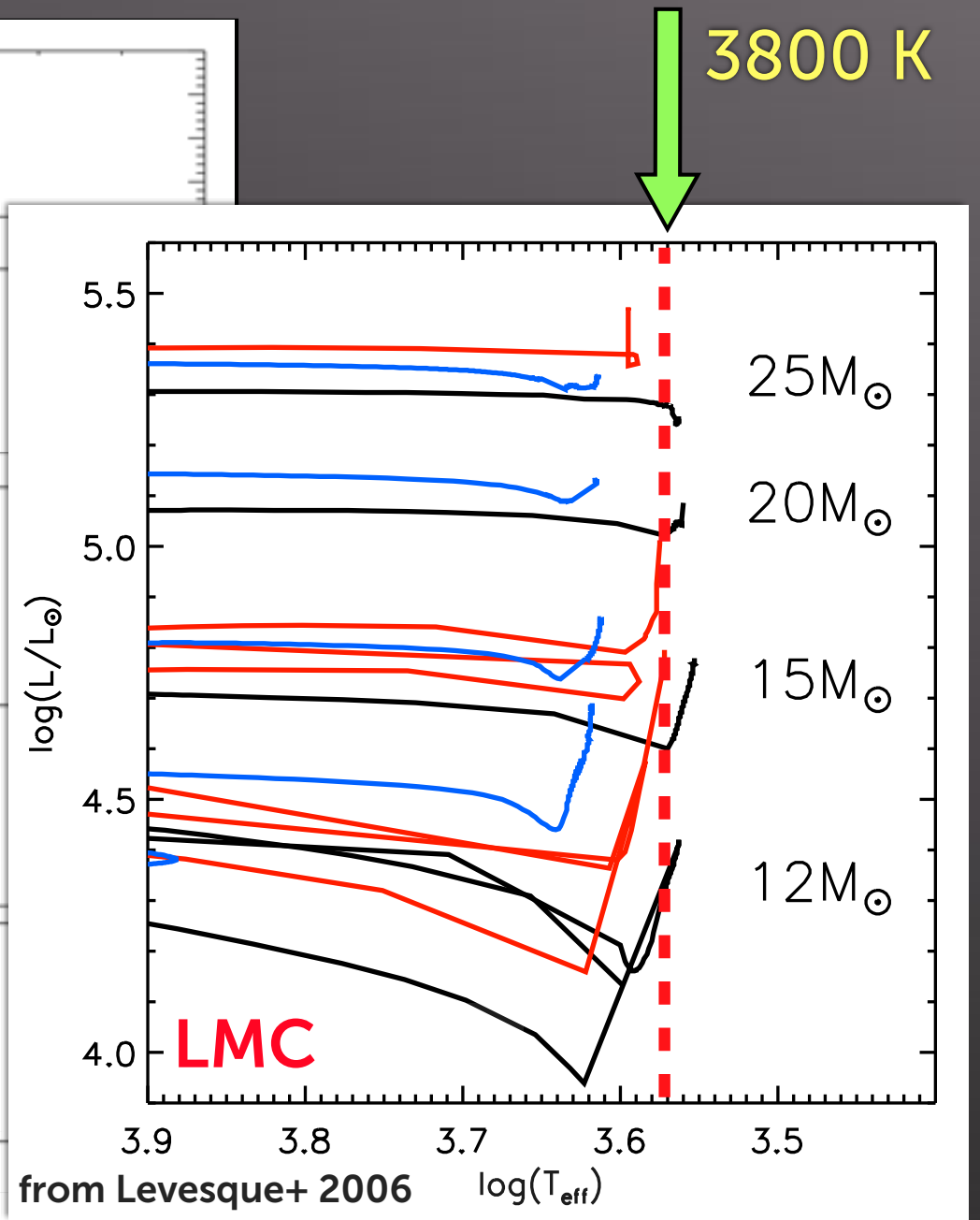
from Levesque+ 2006

Metallicity Effects



Levesque & Massey 2012





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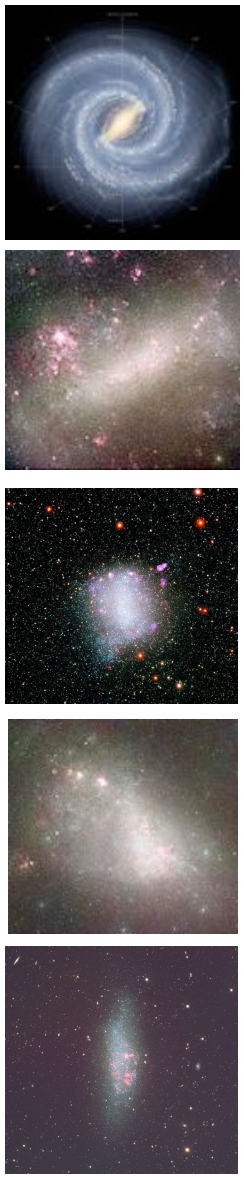
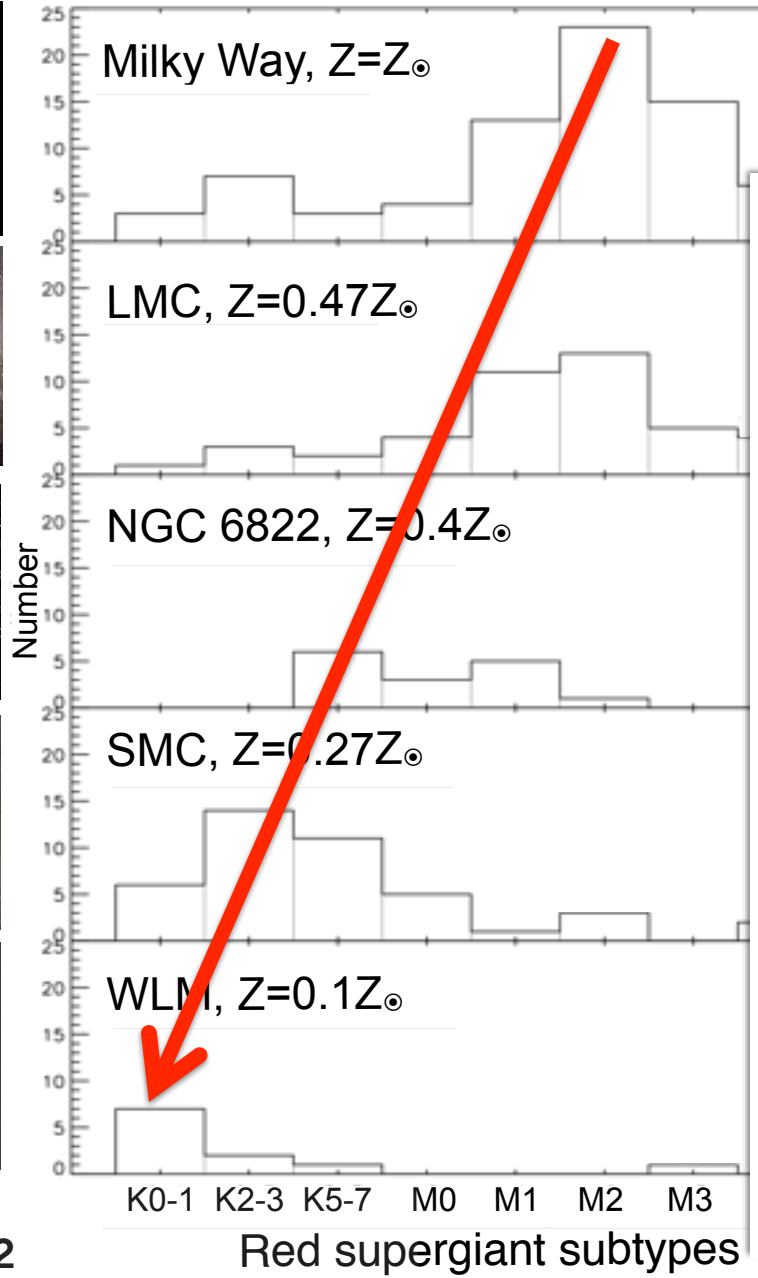
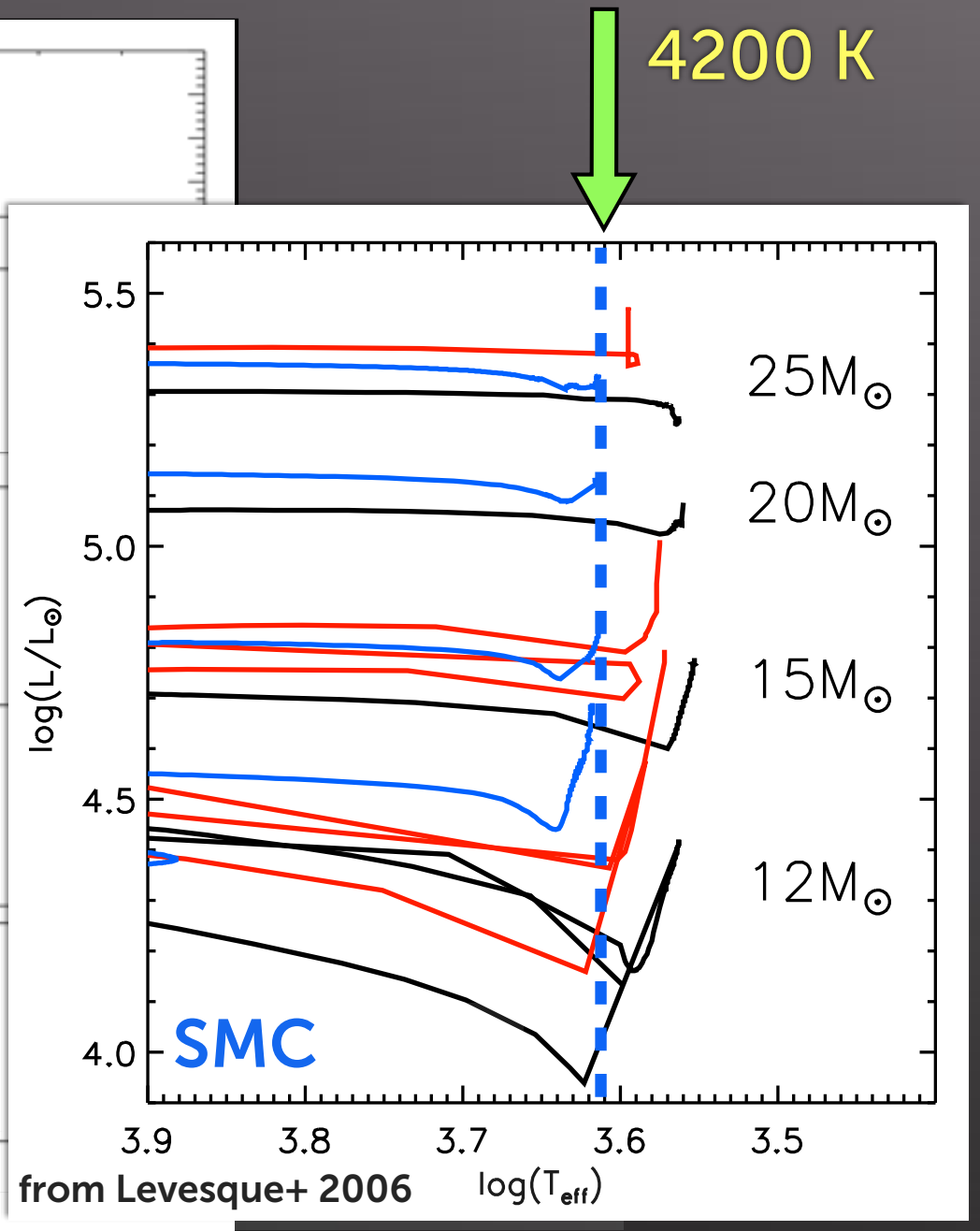
Metallicity Effects



Levesque & Massey 2012





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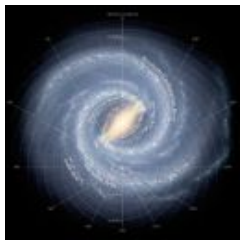
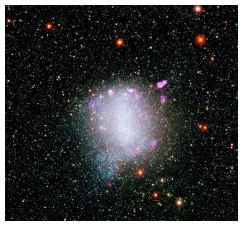
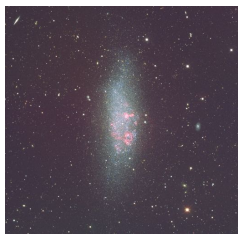
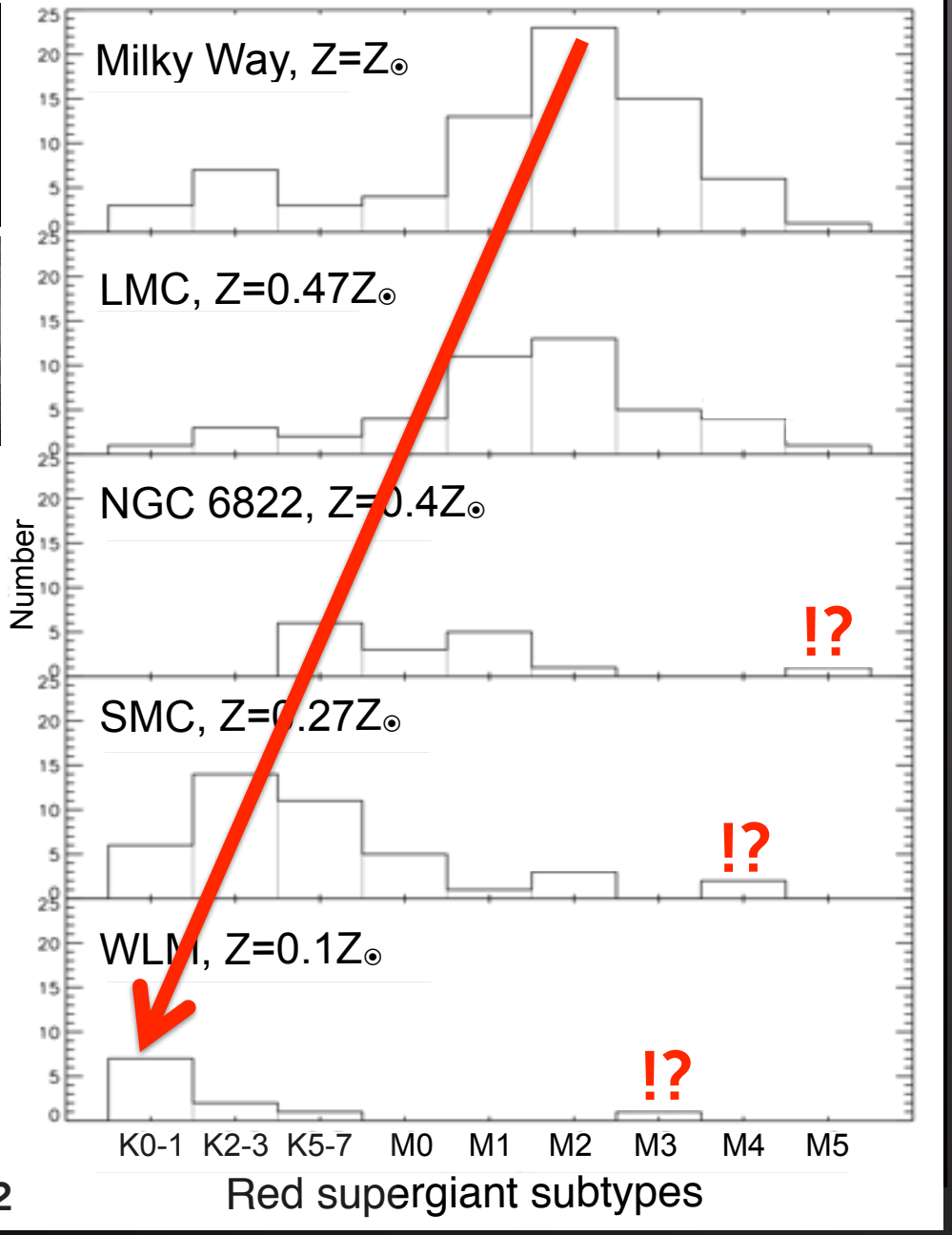
Metallicity Effects



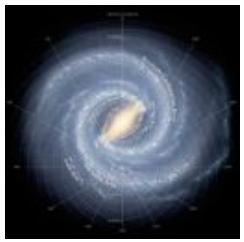


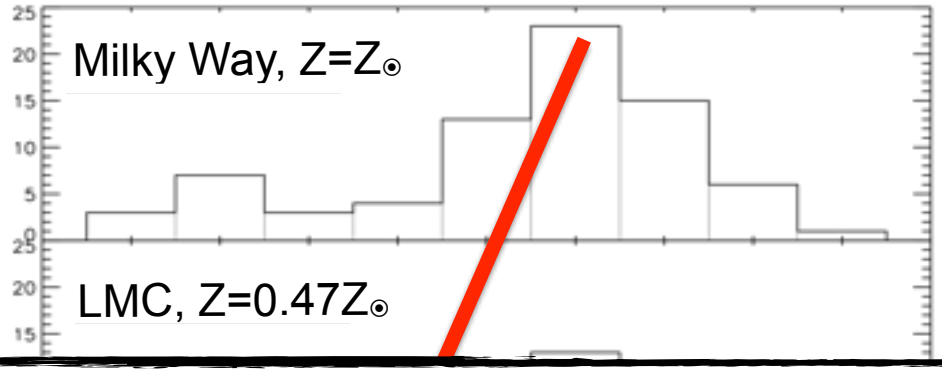


Levesque & Massey 2012



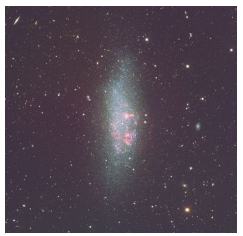
Metallicity Effects

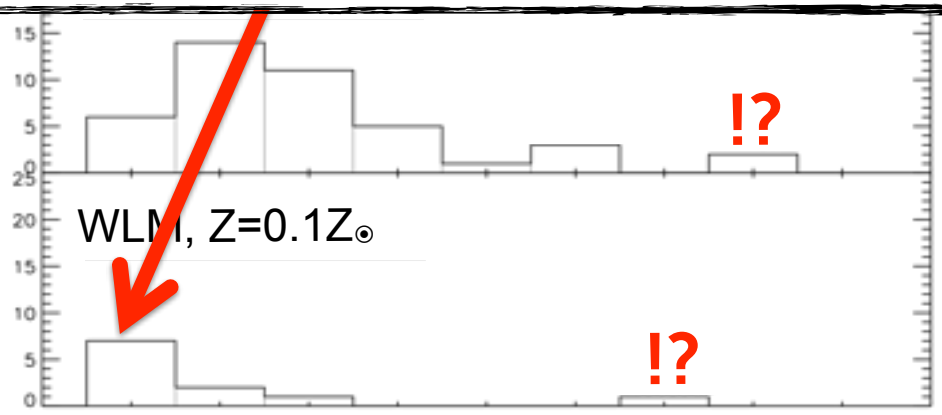




"...Years ago, Kip Thorne and myself 'invented' theoretical models of stars...

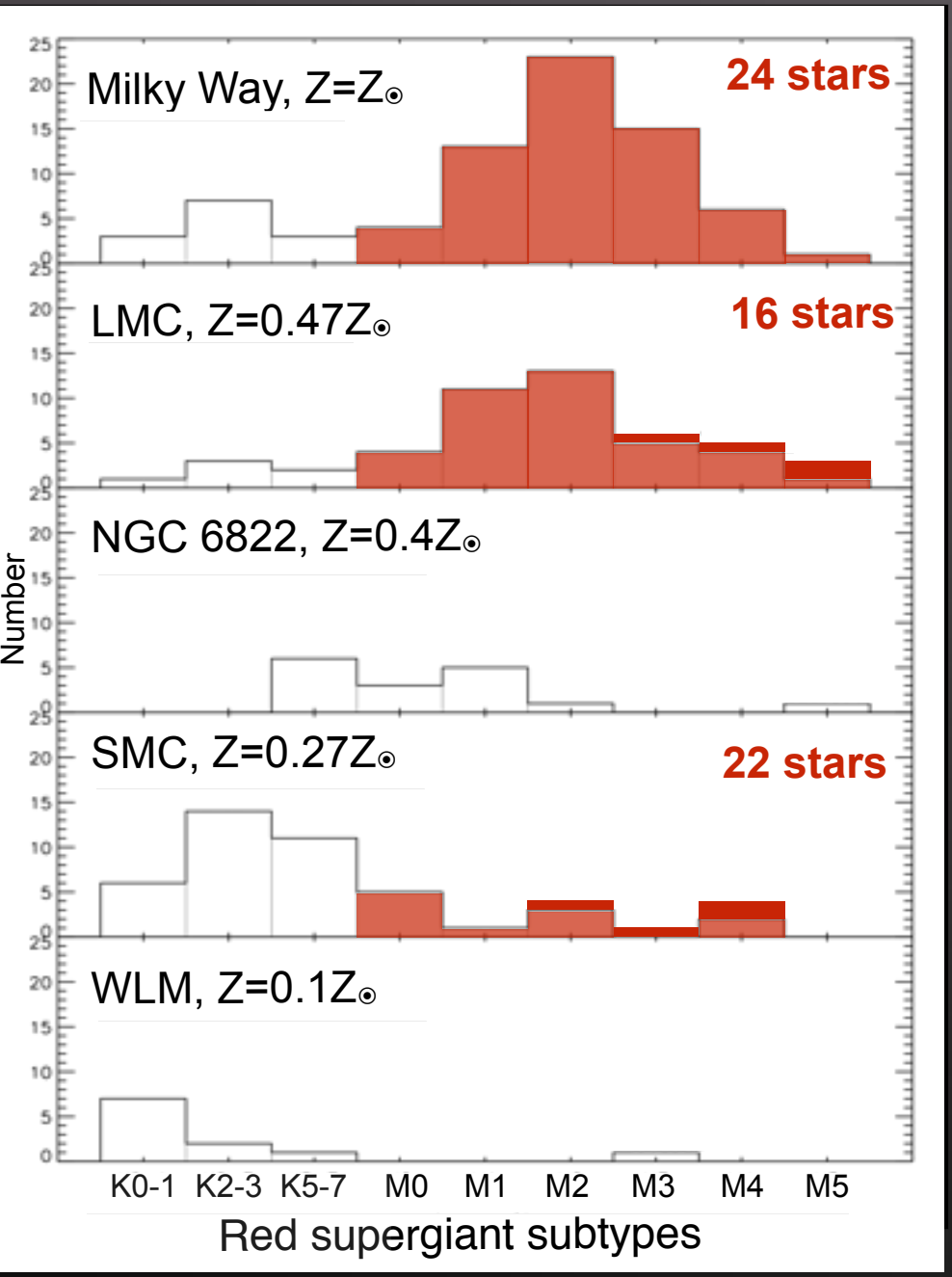
Please let me know if there may be some interest in pursuing these lines of enquiry." - Anna Żytkow





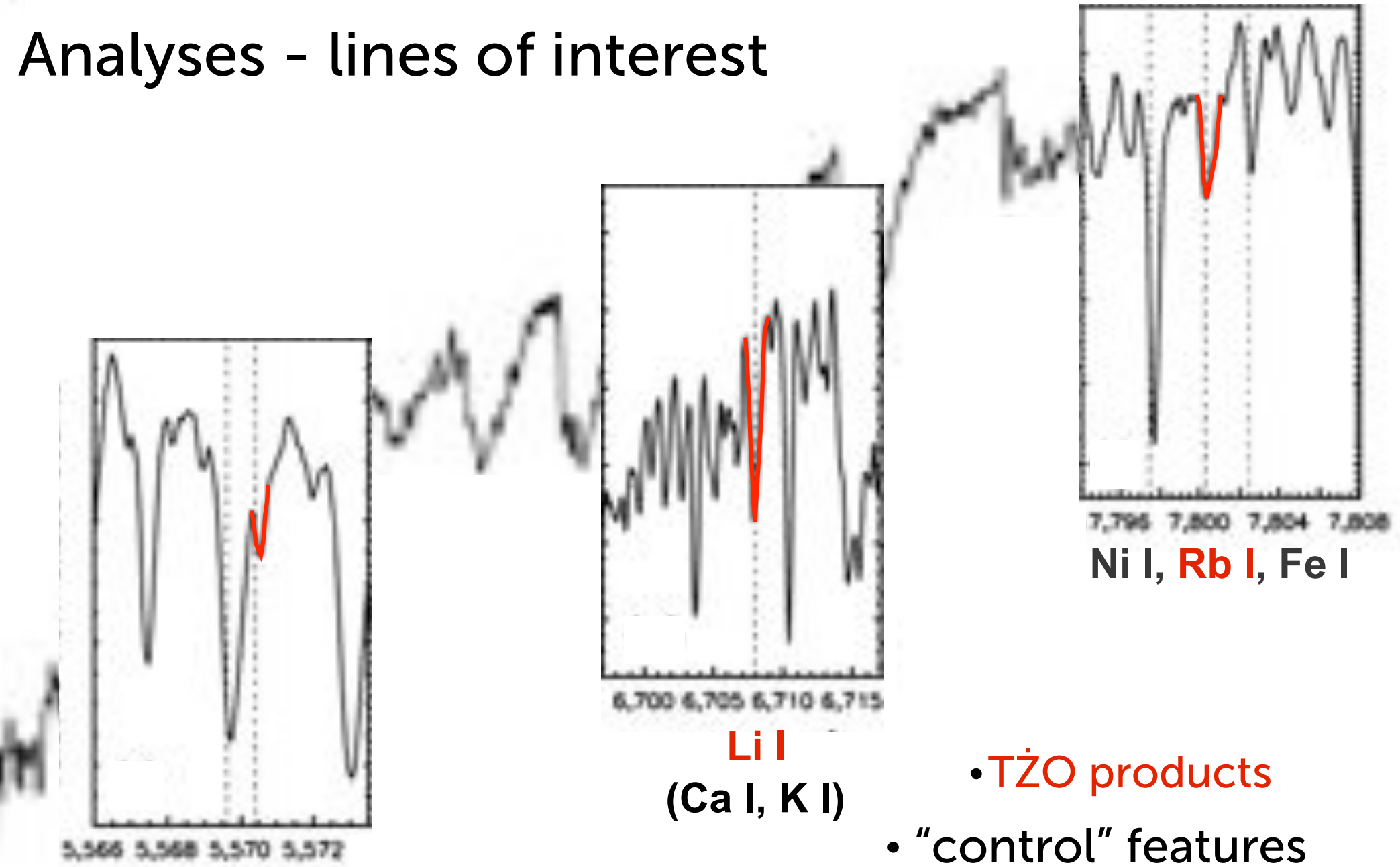
Levesque & Massey 2012

We selected the most likely candidates from our Galactic, LMC, and SMC samples...



Reobserved with both high- and low-res spectrographs...

Analyses - lines of interest



Fe I, **Mo I**

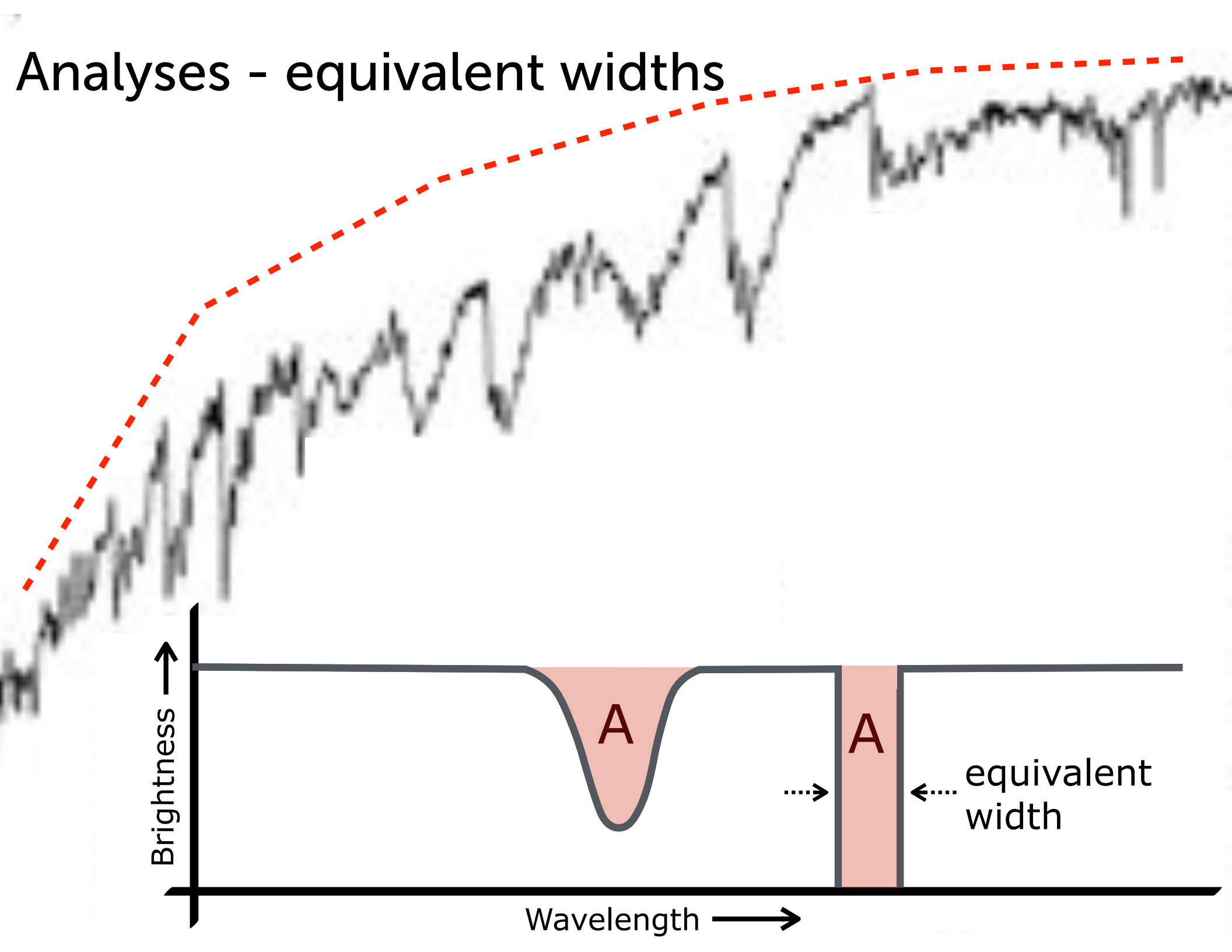
Li I

(Ca I, K I)

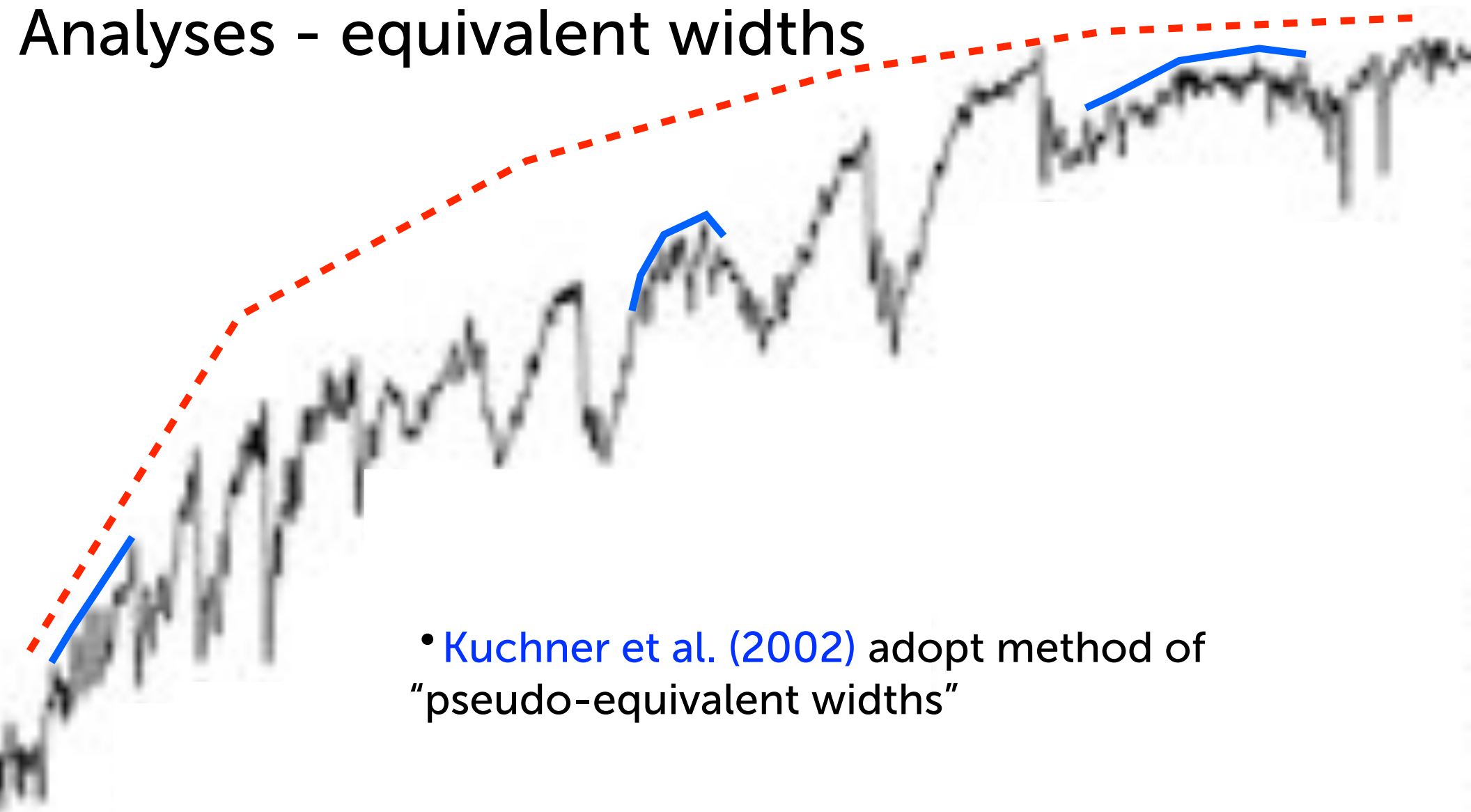
Ni I, **Rb I**, Fe I

- TŻO products
- "control" features
- measure equivalent width ratios of TŻO/control

Analyses - equivalent widths



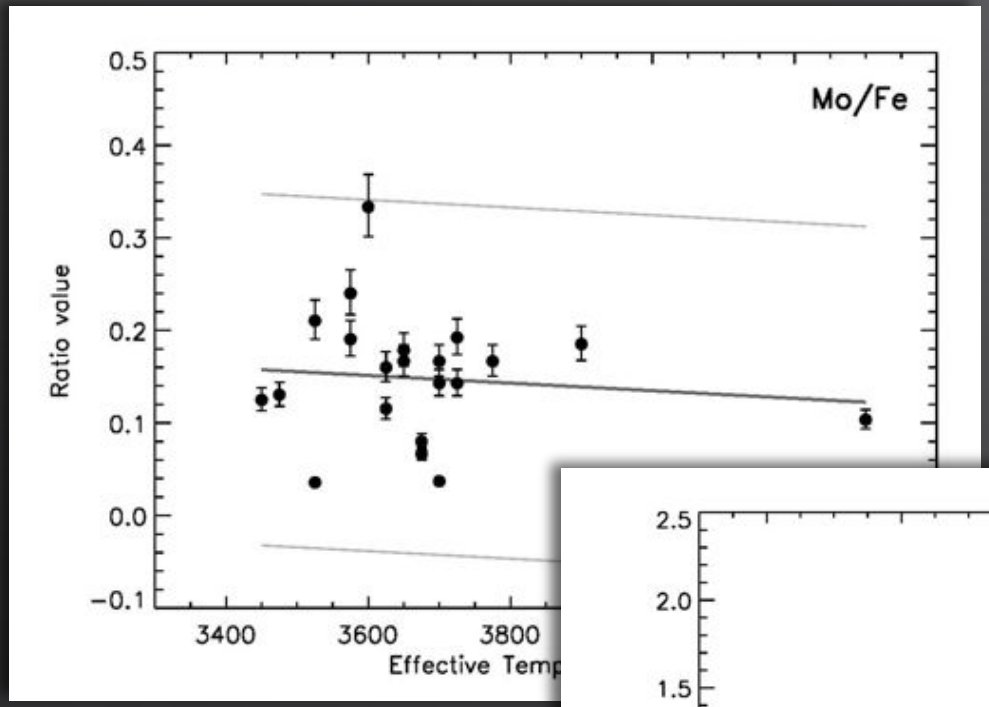
Analyses - equivalent widths

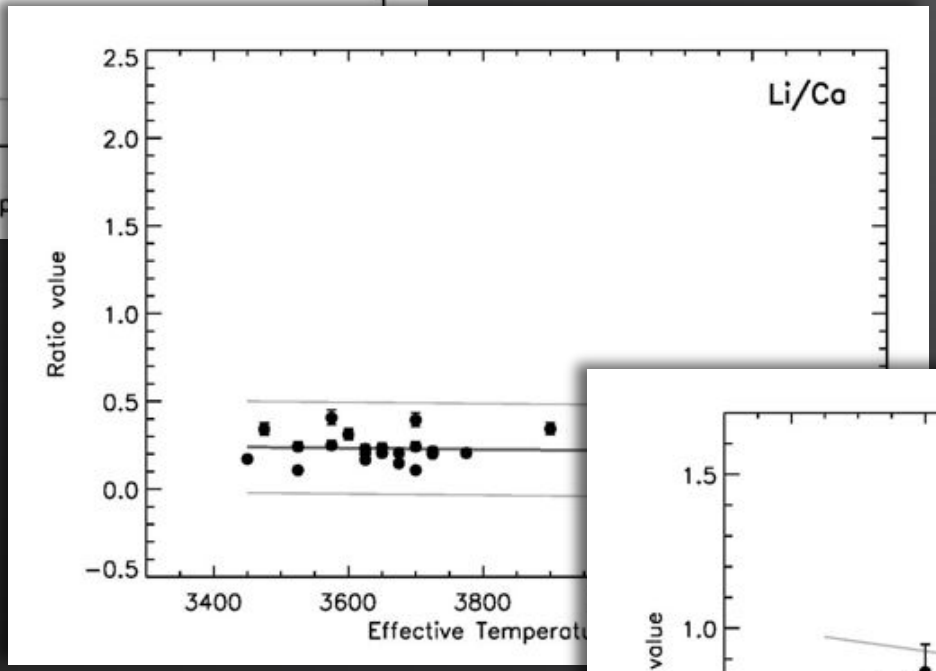


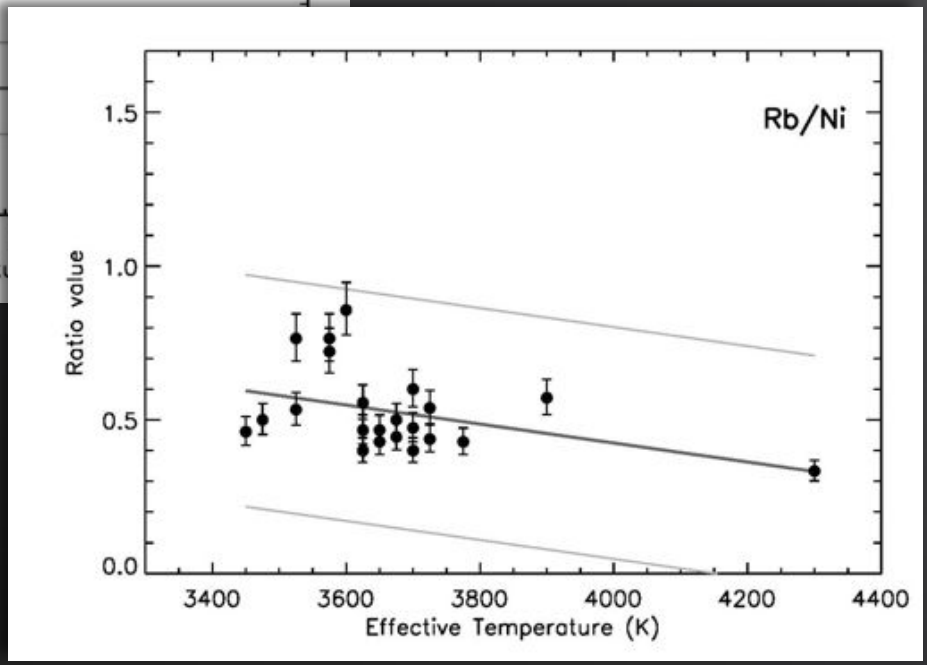
- Kuchner et al. (2002) adopt method of "pseudo-equivalent widths"

- definitions are based on the same features in each spectrum

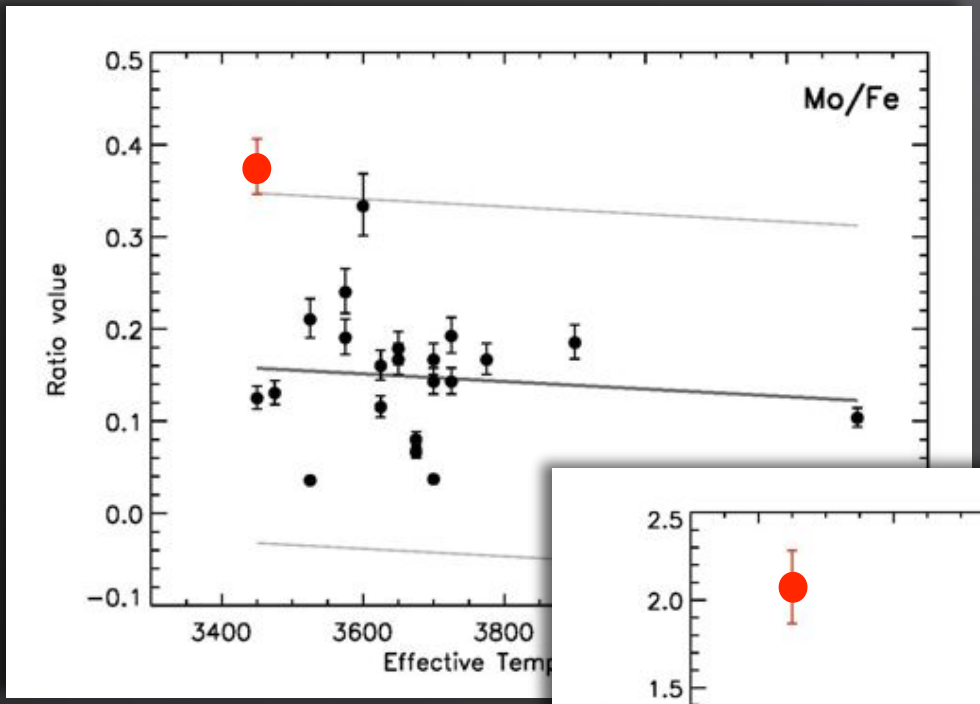
- all spectral features used depend on T_{eff}...

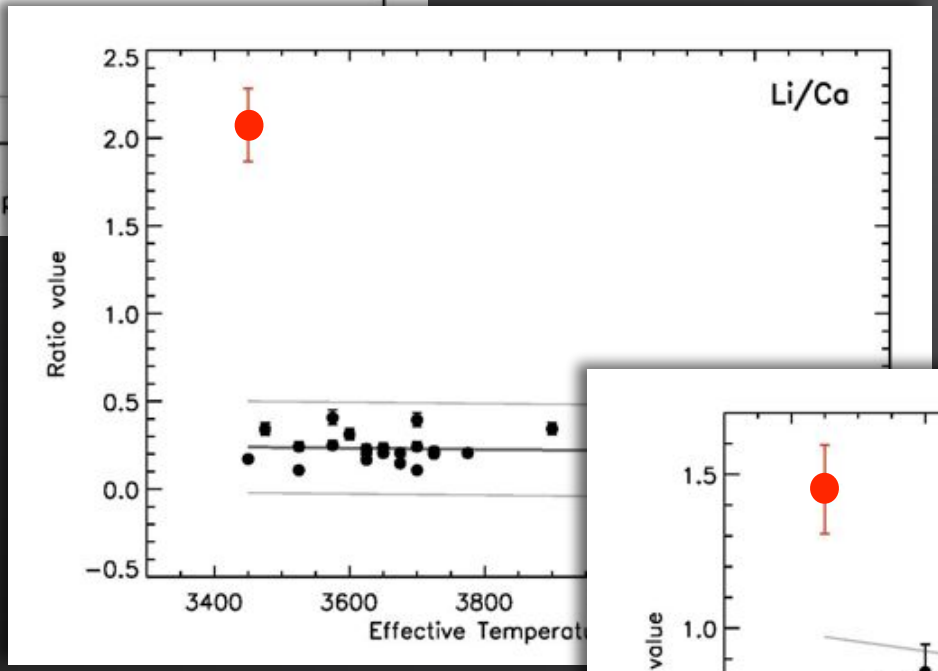

Mo/Fe
Ratio value
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
3400
3600
3800
Effective Temp

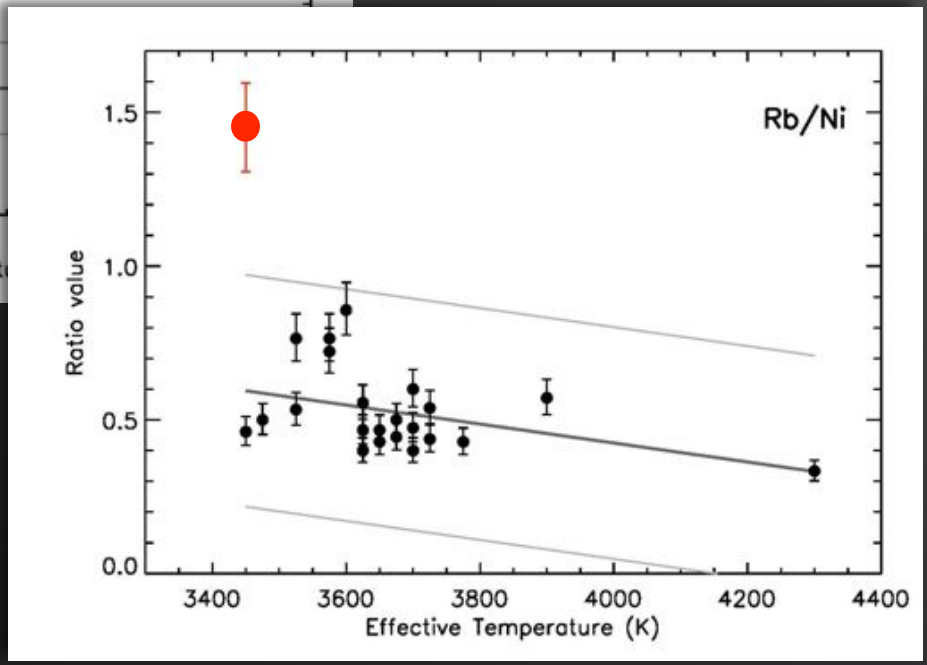

Li/Ca
Ratio value
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
3400
3600
3800
Effective Temperatu

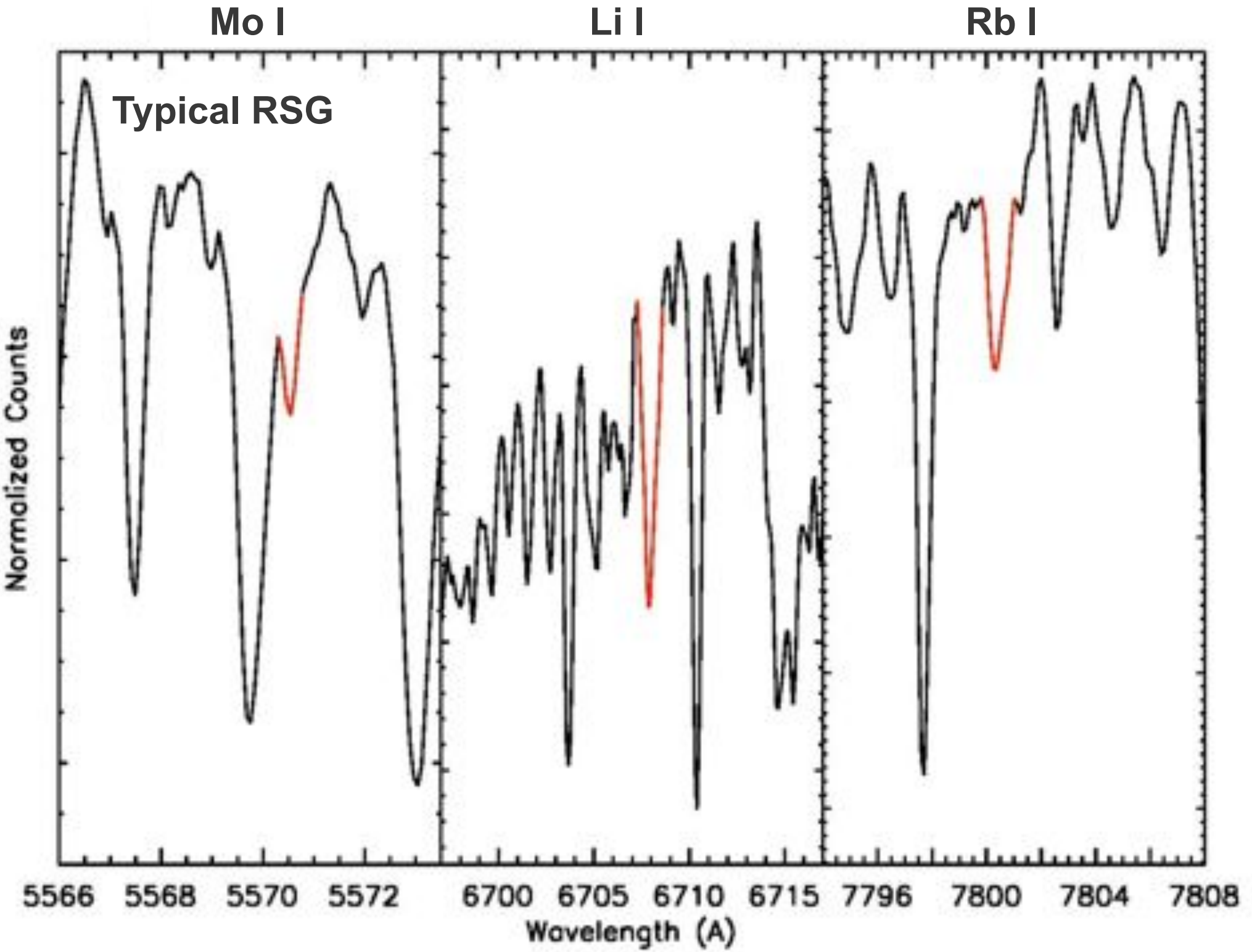

Rb/Ni
Ratio value
1.5
1.0
0.5
0.0
3400
3600
3800
4000
4200
4400
Effective Temperature (K)

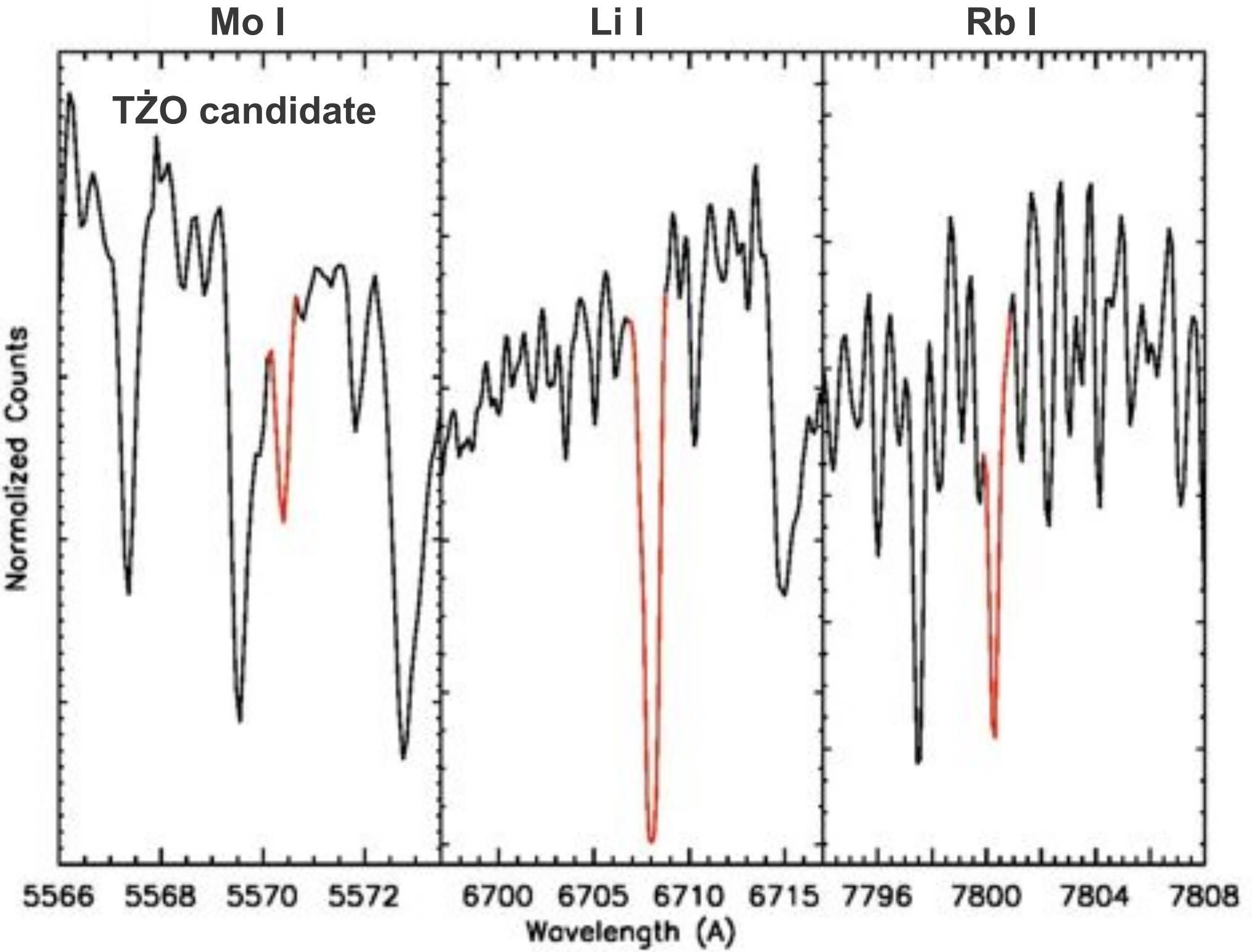
HV 2112; TŻO candidate!

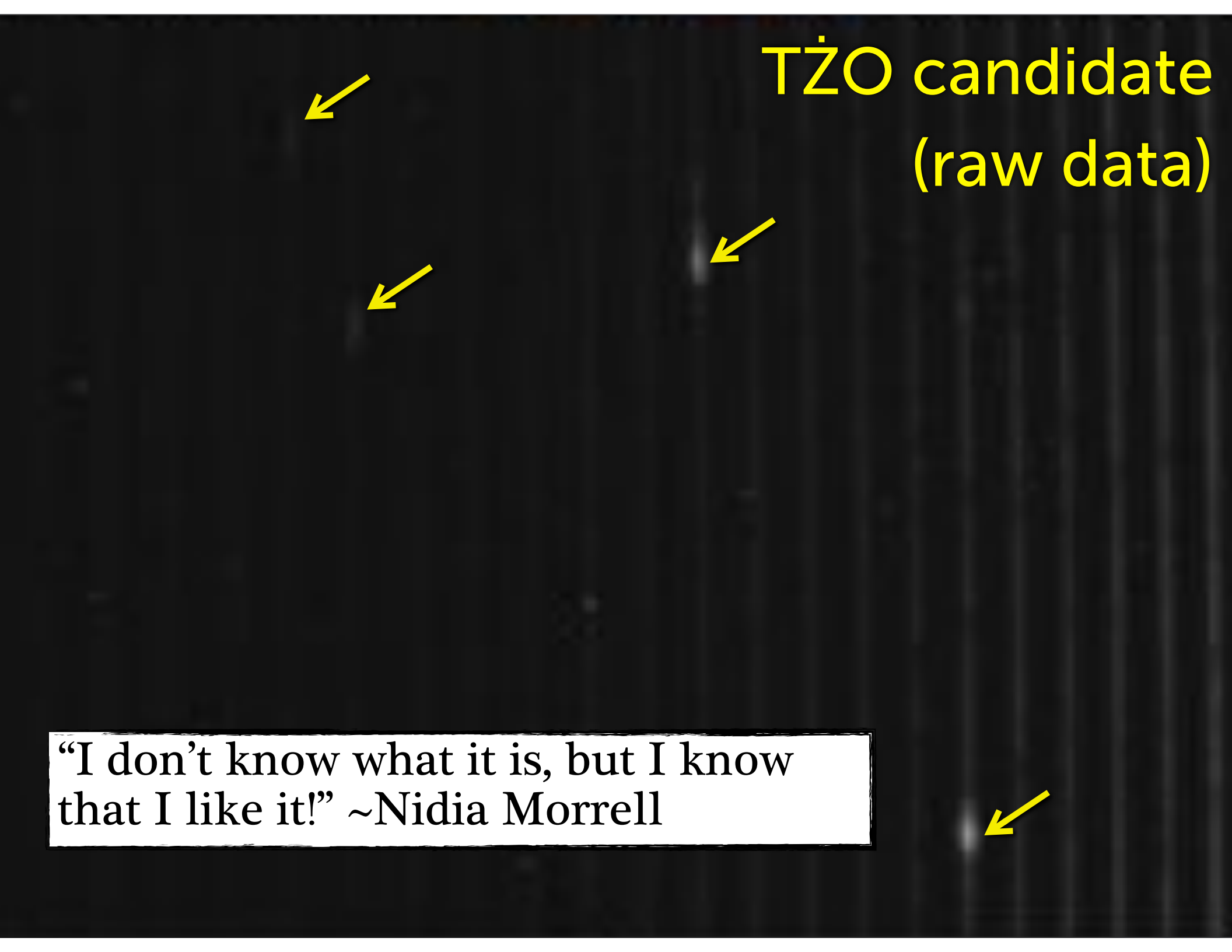


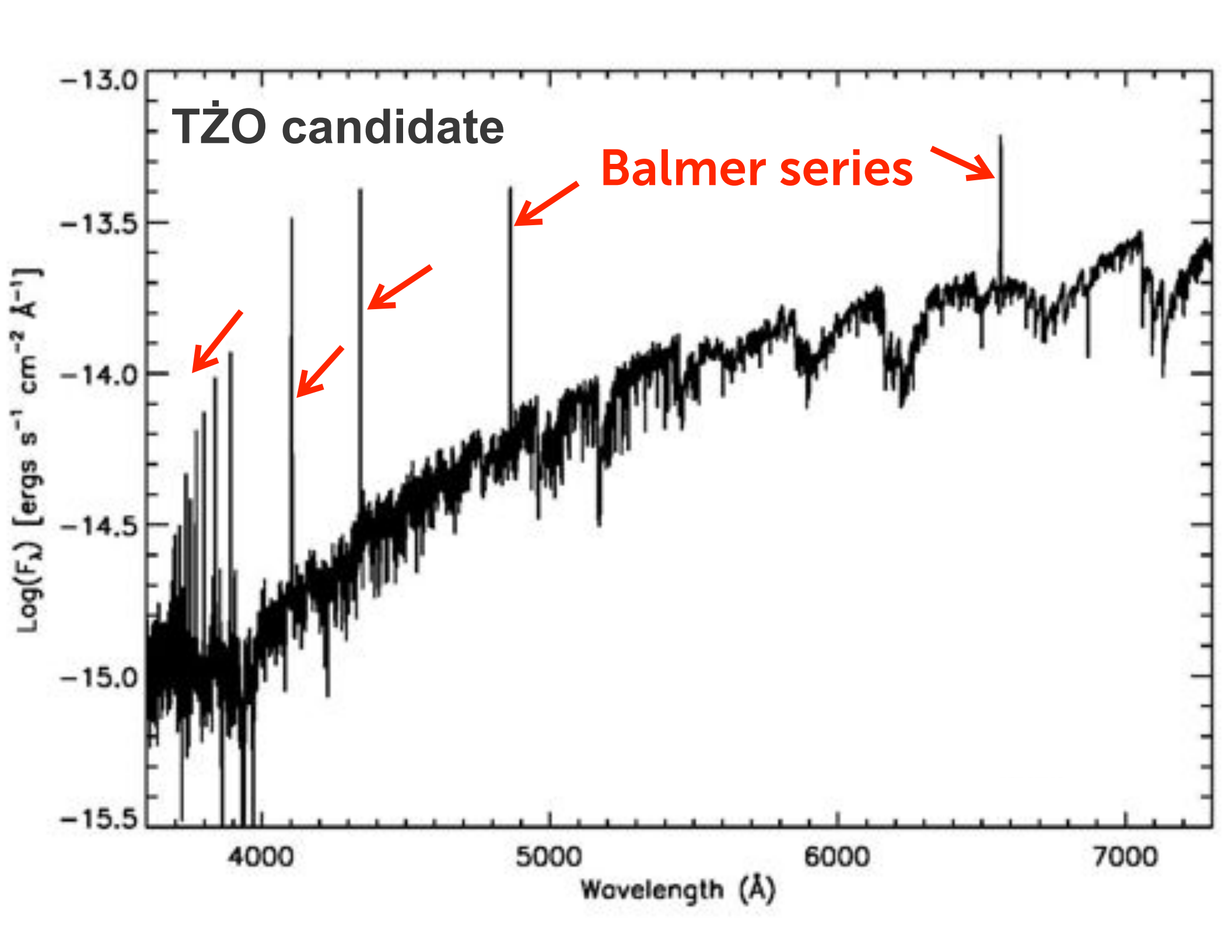





Mo I
Li I
Rb I
Typical RSG
Normalized Counts
5566
5568
5570
5572
6700
6705
6710
6715
7796
7800
7804
7808
Wavelength (A)


Mo I
Li I
Rb I
TŻO candidate
Normalized Counts
5566
5568
5570
5572
6700
6705
6710
6715
7796
7800
7804
7808
Wavelength (A)


TŻO candidate
(raw data)
"I don't know what it is, but I know that I like it!" ~Nidia Morrell


TŻO candidate
Balmer series
−13.0
−13.5
−14.0
−14.5
−15.0
−15.5
Log(F_λ) [ergs s^-1 cm^-2 Å^-1]
4000
5000
6000
7000
Wavelength (Å)

But couldn't it be a...

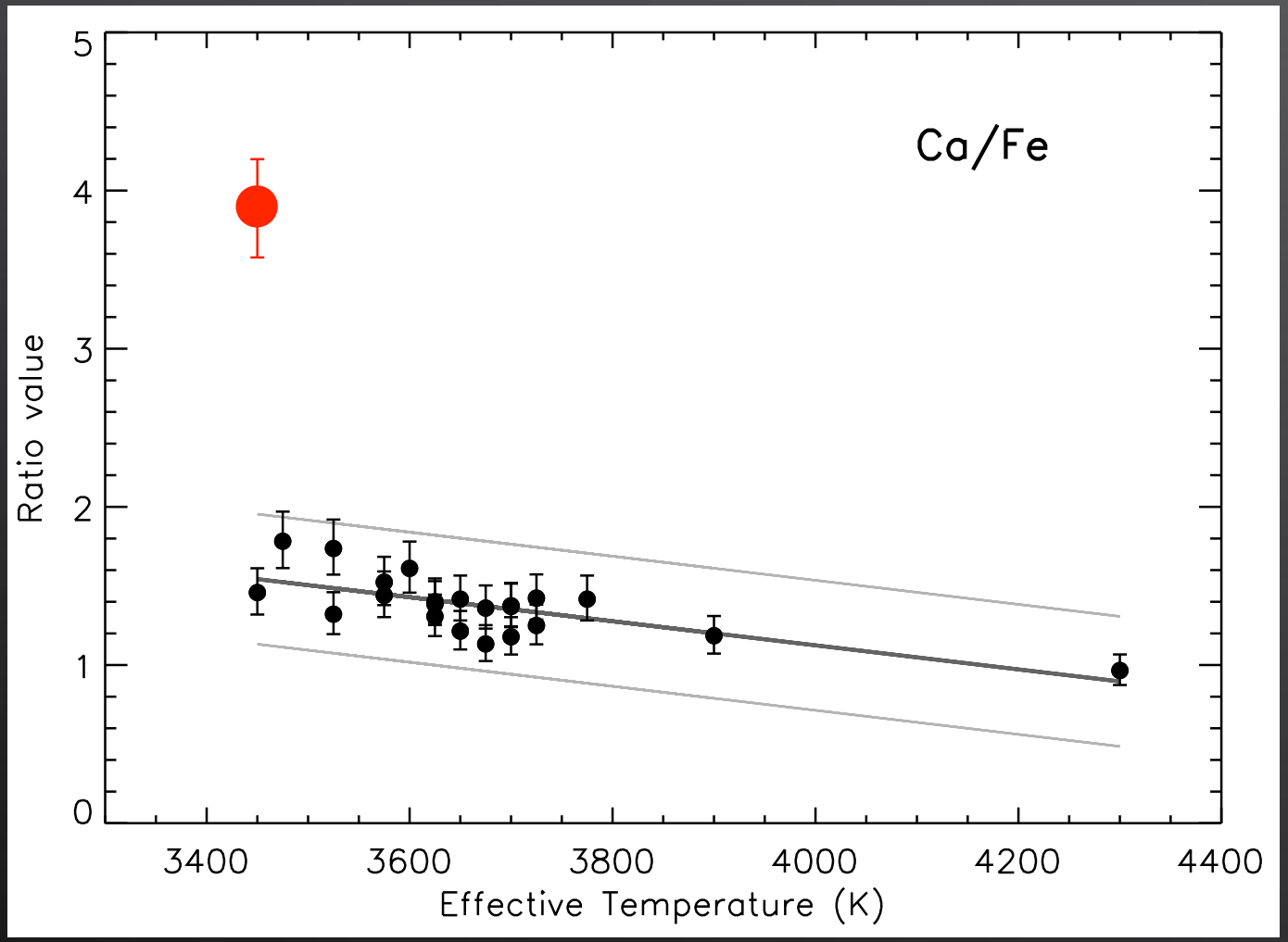
lower-mass giant star in the SMC/Milky Way?

- quite unlikely that a giant in the Milky Way halo would just happen to match the exact motion of the background SMC
- still would not explain element enhancements

(giant stars cannot produce Ca...

...but TŻO <u>formation</u> can!)

Tout et al. (2014)



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foreground dwarf?

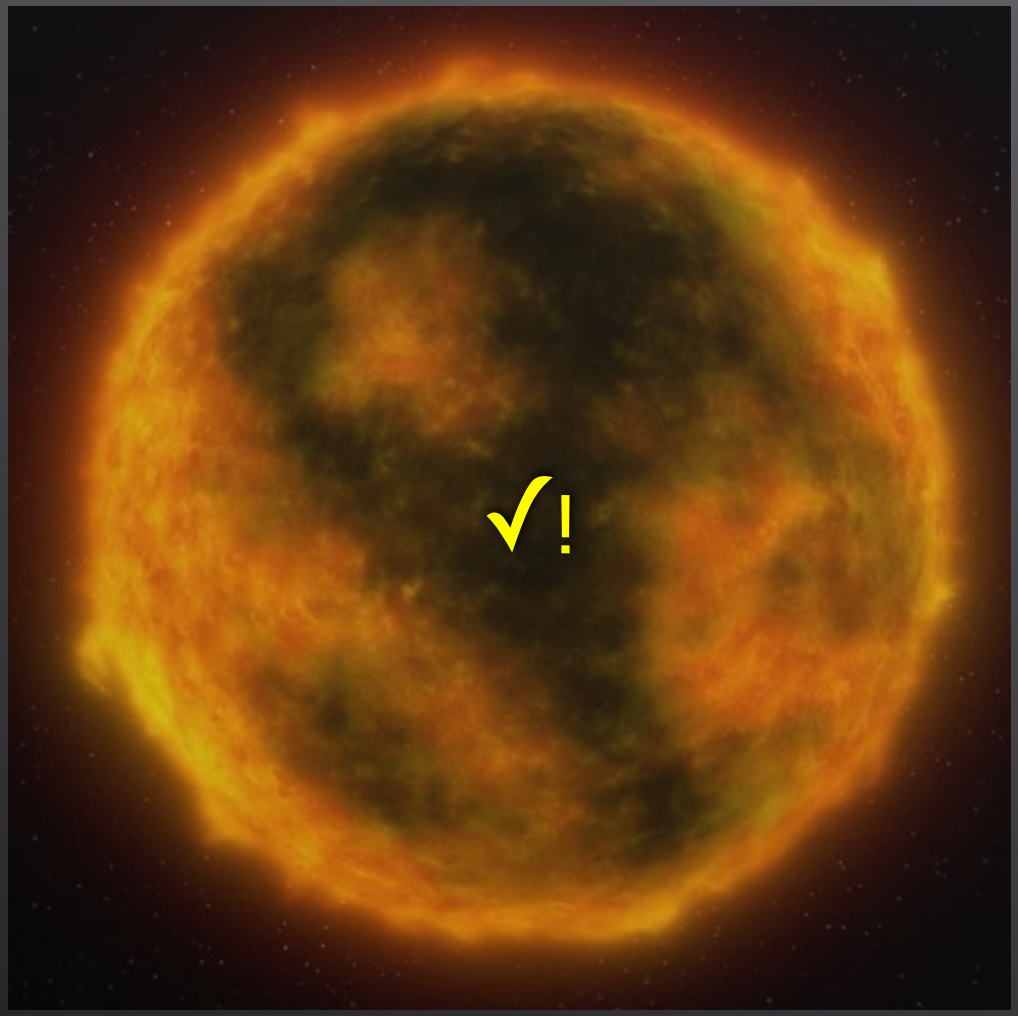
- radial velocity of 157 km s^{-1} agrees with SMC kinematics
- not a flaring M dwarf; Balmer emission lasted over 2 nights

some kind of strange binary?

- not a binary within an ionized common envelope (lacks [NII], [OII], [OIII], etc.)
- OB companion strong enough to produce the Balmer spectrum would produce a strong blue continuum

Properties of our TŻO Candidate

- ☑ cool and luminous, lying at or beyond the Hayashi limit for massive stars (Thorne & Żtykow 1977)
- ☑ strongly mass-losing as a result (van Paradijs et al. 1995)
- ☑ potentially more common at low Z (Linden et al. 2010)
- ☑ unique chemical profile (Biehle 1994)



This star represents the most encouraging detection of a TŻO to date.

The existence of TŻOs would have profound implications for stellar astronomy.

- completely new model of stable stellar interiors
- a new fate of massive binaries
- new nucleosynthesis channels for Li and heavy elements

Discovery of a Thorne-Żytkow Object Candidate in the Small Magellanic Cloud

Emily Levesque

University of Washington

Philip Massey (Lowell Observatory), Nidia Morrell (LCO), Anna Żytkow (Cambridge)

"Extraordinary claims require extraordinary evidence."
- the "Sagan Standard"

Arizona State University

Apr 27, 2016

The existence of TŻOs would have profound implications for stellar astronomy.

- completely new model of stable stellar interiors
- a new fate of massive binaries
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What's next?

- Compute modern models of TŻO interiors
- Searching for additional candidates and proto-TŻOs
- Identify TŻO populations in (and beyond) the Local Group

Other questions...

- what are the properties of proto-TŻOs?
- what are the lifetimes of TŻOs?
- what is the terminal product of a TŻO?

More fun questions...

- What are TŻO evolutionary tracks like?
- How do they contribute to the chemistry of the universe?
- How many are there?
- How do TŻOs affect models of clusters? Stellar pops? Binaries?
- Are their numbers Z-dependent? Are there more at high z?...